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Nuclear Aunt Sally?

ROLL up . . . roll up . . . roll up . . . three balls for sixpence . . . no skill required . . . anyone can try. The season of fairs and fêtes is in full swing and the full forces of domestic coercion are assembled to persuade one to attend. While putting in our dutiful stint we have observed a surprisingly old-fashioned appearance about the functions we have attended. In not one case have we found the skittles, the crockery or the coconuts replaced by models of Berkeley or Bradwell—or even Aunt Sally replaced by the Lord Mills. It seems unenterprising on the part of the various organizers that the popular current sport of slinging mud at our nuclear building policy should not be made available to the masses. Or is it possible that the organizers believe that the public preserve a more balanced approach to the subject?

Within the past week we have read in two worthy publications statements implying that our nuclear building programme is an embarrassment to our general economy and a reason for the discouraging state of our export drive. If this be remotely true then our economy really is in a parlous state and no juggling of the bank rate is going to make any difference. Even cursory examination of the facts, however, must show that the current outcry is emotional and much more to be deplored than the over-optimism which had evoked the criticism. At least this had the merit of being forward looking and constructive whilst the opposition is very largely retrograde and destructive.

Agreed, the capital cost of nuclear plants is much above their conventional counterparts, but if this country cannot invest in high capital cost plant to gain the benefit of low running costs then we must reconsider our standing as an industrial nation. One of the great advantages of being a highly industrialized country is that by making big capital investments ultimate economies accrue, be this in power engineering, motorcar production, chemical engineering or indeed any other enterprise. A policy of low investment and high maintenance and running cost is the policy of the pauper and is one of the reasons why he remains a pauper.

We should have thought it unnecessary to quote once again the published figures for generating costs for nuclear stations as compared with those for conventional plant, but presumably only by repetition will the misunderstandings be cleared up. We make no apologies, therefore, for quoting from the figures given by Sir Christopher Hinton in his lecture "The Evolution of Nuclear Power Plant Design" at the Royal Society's Tercentenary Celebrations.

In this paper the trend in the cost is traced of fossil-fired steam power plants from the earliest days and emphasis is laid on how this followed the progressive rise in top temperature of the steam cycle. It is acknowledged that this is not wholly responsible for the falling costs but the advance to higher temperatures is the backbone of developments. The prediction of generating costs in the future must, of course, contain a number of uncertainties—not least of which is the price of coal, and even the most passionate coal enthusiast does not see this coming down in spite of the large government subsidies for modernization of the mines. At the same time estimates of fuel element life must be regarded as conservative, yet even so the break-even point for nuclear with coal is shown as 1966 at 75% load factor and 1970 for 60% load factor.

It must also be noted that the capital cost figures used by the CEGB differ by as much as £7 million or more from the contract price. This is not just for Berkeley and Bradwell, where complete cores have had to be replaced and much alteration made to the instrumentation, but even to Dungeness where construction has yet to begin. Part of this can be accounted for by the costs of maintaining and building up a nuclear staff, actual site costs prior to construction, the provision of ancillary plant like switchgear—normally a separate contract—and allowance for increase in materials and labour costs during construction. It is still difficult to make all these extras total the necessary amount and there must be several £ million ear-marked for contingencies, the payment of royalties (reputedly £2.5 million on a 500 MW station) and fees to the U.K. AEA for consultancy.

But putting these figures on one side for the moment, surely what must be considered is the development potential. Reductions in the capital cost of conventional plant result in only minor reductions in the cost per kWh sent out: the dominating factor is the cost of coal. As this becomes more difficult to mine, as wages rise, as the demand for built-in safety features in the mines increases to bring them in line with the more modern industries (like nuclear engineering) so this cost will go up and we can be in for some rude shocks in 10 years' time. Even if there are no major crises we shall be very fortunate if the coal-fired plants now under construction are not consuming fuel at a price much above today's figure, before they end their useful life. And all the time one of this country's most valuable raw materials is literally going up in smoke. We may see some increase in the thermodynamic efficiencies of plants but it is difficult to believe that these will be much more than marginal or, more important, that they will not be reflected in nuclear plant operating on similar steam cycles.

With reactors, however, the very fact that their capital cost is high shows that there is ample scope for improvement. The progressive decrease in the contract figures from Berkeley to Dungeness is evidence of the validity of this statement, but the reduction would not be possible if there had not been Hinkley Point and Trawsfynydd in between. There would not have been the competition, the commercial

justification for assembling teams able to undertake the integrated design nor the experience on which to base the steady advances.

The modest steam conditions that are to obtain in Dungeness (less than 400°C) as against those commonplace in modern fossil plant (565°C) again show clearly the considerable room for improvement, but higher temperatures will not evolve from thought alone; they must be approached step by step. That they will be achieved in the next decade is quite definite—provided there is no break in the continuity of development and building. On the fuel side we can look forward to a lowering in fuel element manufacturing and processing costs for many years and there are good grounds for believing that the life-time and costs of the fuel for even our first nuclear stations will be much more attractive towards the end of their life than they appear in the present calculations.

It is indeed remarkable that after only 20 years of development and construction, nuclear power plants will be able to compete on equal terms with fossil fuel devices which have been under active development for 200 years. We must remember that the early experimenters and builders of prime movers also encountered vigorous opposition and there were many critics arraigned against them to prove that horse and human power would remain supreme. There is always room also for people to complain that any programme is too fast or too slow and we must admit that there are many programmes which should never have started. But where the ultimate gain is so self-evident no good can come of the continuous ill-informed bombardment to which the nuclear programme is at present being subjected.

We are a little surprised to find Sir Christopher himself expressing disquiet at the cost of the R and D work which will lead to the fall in unit cost. It seems irrelevent to quote this figure as a percentage of the capital plant installed rather than in terms of the overall saving. If one is substituting a plant the capital cost of which is dominant for a system dependent upon raw material costs then it would be quite wrong for the same proportion of R and D effort to be expended on the two constructions. The only significant calculation must be whether one will see an adequate return for one's investment. Bearing in mind that a saving of 0.1d./kWh spread over 20 years represents a saving on a single 500 MW station of nearly £20 million, it is clear that the dividends to be gained from R and D are large. But the opportunity to make these savings must be there and they are much more self-evident in a nuclear plant than in a coal plant. If Sir Christopher is concerned that the figure he quotes of 30% (*per se*) is too high then the remedy is in his own hands. It can quite simply be halved if he doubles the rate of nuclear station building that he is at present contemplating.

Not Another Geneva

INEXORABLY apparently, the forces promoting another Geneva are moving towards their target. It can still be averted but the probability of there being a repeat performance of the 1958 conference in 1962 seems high. Looking back to the unanimity of opinion expressed in 1958 against any suggestion of another mammoth conference it seems incredible that the subject needs discussion. 1962 could hardly be a worse choice with the 6th World Power Conference in Australia scheduled for October (the Canadian meeting was ruined by the 1958 Geneva) and the new Foratom determined to organize a Congress in Paris in the same year.

The first international conference in Geneva was a great boon to the whole technology. For the first time, matters which had been cloaked under heavy security regulations were discussed publicly and scientists from all over the world who had not been in communication for many years were able to begin talking freely on the work on which they had been engaged. This did not happen all at once, but there is no doubt that the 1955 conference was the signal.

The 1958 conference was a necessary venture partly because it seemed so desirable to repeat the 1955 effort and partly to clarify many of the issues that had been raised before. A direct result was that thermonuclear work also became emancipated. It became widely recognized that this was a science which could greatly benefit from international collaboration and the commercial implications were so long-term that research in secrecy could only hamper and could not benefit its eventual exploitation. The French made strenuous attempts to persuade the major nuclear powers to disclose the techniques they had adopted for enriching uranium, but were unsuccessful.

Should a third international Geneva succeed in doing this there might perhaps be some justification for holding one, but there appears no reason why an international conference called solely to discuss this topic could not achieve the same ends and at the same time be technically much more efficacious.

Between 1955 and 1958 there were few international meetings of significance and it was natural that the IAEA should wish to sponsor a grand event, but since 1958 the IAEA's policy has been to organize a considerable number of international meetings on specific subjects or co-ordinate the activities of other bodies engaged on this task. A typical example is the conference on medium and small power reactors in Vienna this month.

The all-embracing conference is too big, too expensive and too time-consuming. The dislocation to research organizations before and during the event is enormous and it is many months before much of the material can be assimilated—if it ever is.

It is presumably politics behind the move towards this third effort. The popular explanation is that the United States wish to have a platform on which to exhibit their enormous wealth and to meet the Russians in a prestige battle. How much truth there is in this is difficult to evaluate, but the underlying motives can certainly not be technical. It is possible that the main reason is inertia, that the movement has started and nobody is prepared to risk unpopularity by stopping it.

Editorial Vacancy

NUCLEAR ENGINEERING will shortly have a vacancy on its editorial staff for a young engineer with a broad interest in nuclear matters. Actual experience in the preparation of material for publication would be an advantage. Work would be centred on the London office but the successful applicant must be prepared to travel. Please write in the first instance stating age, background and experience to The Editor, Nuclear Engineering, Bowling Green Lane, London, E.C.1.

DIGEST...

Surveying Significant News

The IAEA and Correlation of Fault Data

In this issue three further contributions are made to the problem of spurious instrument information and the recording of fault data on reactors. The AERE scheme for classifying the fault data from all its reactors on a punch-card system is described. If this recording could be made uniform throughout the major operators of nuclear reactors the correlation of experiences in this field would be greatly eased; this would seem to be a suitable project for the IAEA. We suggest that a conference be called to discuss the subject with a view to drawing up a code of practice.

Chooz Contractor Selected—Pressurized Water-type Chosen

The contract for the erection of a 242 MW nuclear power plant at Chooz in France near the Belgian border has after all been awarded to the consortium consisting of Westinghouse, U.S.; Ateliers de Constructions Electriques de Charleroi, Belgium; and Framatome, France. The reactor will be a closed-cycle pressurized water plant designed by Westinghouse and the plant will be built for Société d'Energie Nucléaire Franco-Belge des Ardennes (SENA). The station, a natural successor to BR-3, is scheduled for operation in 1965.

European Nuclear Forum Established

The national industrial nuclear associations of France, Belgium, Luxembourg, Italy, Germany and the Netherlands have agreed to co-ordinate their activities and to establish a Forum Atomique Européenne or in short—FORATOM. The association in Switzerland has made an immediate application for membership and has been unanimously accepted, and equivalent organizations in Denmark and other European countries have also expressed interest.

Enrico Fermi Legal Suit Developments

A request has been made to the U.S. AEC and to the Department of Justice to take the necessary legal steps in the United States Supreme Court for a review of the June 10 decision by the U.S. Court of Appeals for the District of Columbia setting aside the Commission's grant of a provisional construction permit to Power Reactor Development for the construction of a fast breeder power plant at Lagoona Beach, Michigan. On July 25, the Court of Appeals denied the petition of the United States and the PRDC for reconsideration of the June 10 decision.

International Ship Rules Published Shortly

Publication of the rules drawn up by the International Convention on Safety of Life at Sea Conference in London in April can be expected within the next few weeks. The rules adopted by IMCO as the result of this Conference are far less specific than those proposed in the Ministry of Transport Report. Little guidance is given to the reactor designer but the necessity for a nuclear cargo safety certificate is laid down and Contracting Governments have a right to inspect the safety assessment of a ship prior to its visit to their country.

OEEC Convention on Third Party Liability Comes Into Force

The necessary five signatures to the European Nuclear Energy Agency's Convention on Third Party Liability in the field of nuclear energy were appended in Paris on July 29 and other members of OEEC will be agreeing to the Convention during the coming weeks. The major problems have now all been resolved and the Convention makes specific rulings regarding the party liable in the event of an accident (be this in the plant concerned or in regard to material being transported to and from the plant), prescribes limits to the extent of the liability in terms of both time and money and defines the right of recourse of both reactor operators and outside bodies. A summary is published on page 404.

First Annual Report of Dragon

The first annual report of the high-temperature reactor project DRAGON, published on August 10, is a 300-page document covering not only the finances and organization of the project but giving considerable detail of the design of the reactor experiment (major details of this design were published in *Nuclear Engineering*, July, 1960, pages 299-315).

Reorganization at Harwell

In view of the number of establishments now coming within the aegis of the research group, Sir Basil Schonland is to relinquish his position as Director of Harwell to concentrate on the more general activity implied in his post as Director of the Research Group. Dr. Vick takes over the detailed running of AERE with Dr. Spence as Deputy Director. Dr. Vick brings to his position a reputation for drive and determination and a clear understanding of his objectives. Whilst it is known that he believes in Harwell being a fundamental research establishment we can expect to see a greater coordination of the activities of the the divisions and a stepping up in the reorientation of the work of the establishment towards a clearer identification with the general nuclear programme.

U.S.-Euratom Research and Development Programme Expansion

Forty-five proposals for research and development work, totalling nearly $7.8 million, have been accepted for contract negotiation within the U.S.-Euratom Joint Research and Development programme. Twenty-eight European and 10 U.S. concerns are represented. The interest of the joint programme to date has been in work related to the boiling water reactor concept and towards plutonium recycling. Emphasis has also been placed on work on uranium and plutonium compounds, fuel development, improved zirconium alloys and heat transfer studies.

International Food Irradiation Information Centre

An international information centre for food irradiation has been established at Saclay in France following an agreement signed between the OEEC European Productivity Agency and the CEA. Functions of the centre include the preparation and publication, in English and French, of a quarterly international newsletter on food irradiation. The centre will serve as a point of contact between scientists, food technologists and governmental and industrial circles. The contract covers a two year period and provides for the payment of NF32,000 towards expenses.

Second Site in North Wales for a Nuclear Plant

Wylfa is to be the site for a second nuclear power station in North Wales following investigations by the CEGB and permission will be sought to develop the site. Three suitable areas for a power station were investigated in Anglesey, at Wylfa, Carmel and Trefadog. The Board have considered these sites together with one at Edern on the north coast of the Lleyn Penisula and have reached the conclusion that Wylfa is the most suitable. It is on the north coast of the island 1½ miles west of Cemaes Bay. The recently revised nuclear power programme means however that the station will not be required in the period up to and including 1966 and so construction will probably begin in 1963.

Final Agreement on Ispra Granted

Final ratification by the Italian Government of the agreement concluded with Euratom for the transfer of the Ispra Nuclear Research Centre to Euratom has now been given. Euratom research teams have moved from Brussels to Ispra on Lake Maggiore, 35 miles from Milan. They are the vanguard of a total staff of 1,500 research workers expected to be in the employ of Euratom by the end of 1962. More than $40 million is to be spent in enlarging the centre over the next two years. Euratom Joint research centres are also being established at Petten in the Netherlands, at the Transuranic Elements Institute at Karlsruhe, West Germany and at the Central Nuclear Measurements Bureau at Mol in Belgium. A European school along the lines of the ones at Luxembourg and Brussels will also be set up by Euratom at Ispra.

Nuclear Installations Regulations now Effective

The Nuclear Installations Regulations 1960, extending the provisions of the Nuclear Installations (Licensing and Insurance) Act 1959, were submitted to Parliament on July 28, and became effective on August 22. Made jointly by the Minister of Power and the Secretary of State for Scotland they prescribe certain classes of installations for the purpose of the Act. Such installations will require to be licensed and the other provisions of the Act, including the provision of cover for the licensees liability by insurance or other approved means, will apply to them. Previously only reactors had been definitely specified but the manufacture of enriched uranium fuel elements and their storage (except incidental to carriage and research) are now included. The Regulations are designed to cover the Rolls-Royce submarine element plant.

Reactor Briefs

The 3MW pool-type reactor at the Venezuelan Institute for Scientific Research went critical during July . . . Criticality has been achieved by the low power assembly for the HTGR studies at the John Jay Hopkins Laboratory.

Spurious Signal Comment

Publication of the Questionnaire sent to Reactor Operators

AS the result of our survey published in June (page 241) on sources of instrument fault, we have received a considerable number of inquiries requesting further details of the manner in which the information was sought and correlated. Some correspondents have pointed out the limitations of the survey and the difficulty of interpreting the results in terms of any particular design without a full knowledge of not only the design philosophy but the specific equipment employed.

With this comment we agree, but we felt it necessary at a first approach to guarantee that specific faults were not related to the particular reactor concerned as we felt that otherwise reactor operators would be chary of providing even the bare information requested. Perhaps this was an unnecessary undertaking but in general there is a hesitancy to broadcast statements relating to the malfunctioning of reactor equipment and there are also difficulties which can arise from, for example, a too literal interpretation of a given set of figures reflecting unfairly upon the equipment manufacturer. It is felt also in some quarters that discussions of imperfections in reactor control equipment can be picked up by non-technical readers and taken as implying a lack of safety in the reactor concerned and by implication that its operation is hazardous. In addition, local pride demands that little publicity be given to both errors in design and mal-operation that could appear as stupidity or carelessness on the part of the people concerned. In these respects there would appear to be a stronger tradition of candour in the United States than in Europe and it has been noticeable that U.S. operators have, on the whole, been the most forthcoming.

In spite of the desirability of relating particular instrument errors to individual reactors we feel we cannot at this stage break confidence and publish more than general trends. We reproduce below a replica of the form that was circulated as additional assistance in the interpretation of the analysis. We have reason to suppose that not all operators either could or did complete sections 4 to 7 on the basis of all spurious information received, irrespective of whether this led to a shut-down or not and, therefore, there is a stronger weighting on those items of plant or control equipment which are liable to trip the reactor rather than merely require the institution of maintenance procedures.

REACTOR INSTRUMENTATION FAULT ANALYSIS

General

Reactor Designation : Type :
Purpose : Date critical :
1 Extent of Xenon override :
2 No. of planned shut-downs per annum :
2 No. of forced shut-downs per annum :
2 No. of shut-downs resulting from spurious information :

3 Brief description of control system :

ANALYSIS OF SOURCE OF SPURIOUS FAULTS

4 In terms of Equipment Type :

Equipment		Reactor trip %	Maintenance only %	Total %
(a)	sensing elements			
(b)	cabling & telemetering			
(c)	electronics			
(d)	interlock circuits			
(e)	others			

7 Ascribable to :

	%
Design	
Maintenance	
Damage	
Human	

5 In terms of Individual Units (a), (b) and (c) :

		%		%		%		%		%		%		%
(a)	ion chambers		pulse counters		temp. devices		pressure devices		flow meters					
(b)	mechanical damage		electrical		pneumatic									
(c)	d.c. amps.		pulse amps.											

6 In terms of Components (c), (d) and (e) :

(c)	valves		transistors		solid state devices		condensers		resistors					
(d)	relays		mag. amps.		connectors									
(e)														

8 Additional comments :

NOTES

The analysis is aimed at determining the source of spurious signals not the cause of genuine reactor faults.

1. Express in terms of time after shut-down during which reactor cannot be restarted.
2. Provided period remains constant, figures need not be reduced to annual values. Please state approximate period chosen.
3. Relevant information comprises number of groups of rods (coarse control, fine control, scram); types of shut-down signal (warning only, controlled shut-down, scram); basic philosophy of control system, e.g. two out of three for nucleonic instruments and some physical instruments or basic auctioneering system; numbers of instruments able to initiate shut-down.
4. This and subsequent sections aim at defining location of spurious signal initiation, whether the instrument fault resulted in a reactor trip or not.
5. Break-down in terms of specific instruments. Additional columns are available for instruments not otherwise defined.
6. Break-down in terms of components where known.
7. An estimation would be helpful if exact figures are not available; space is left for an additional category if required.
8. Relevant commentary could include an assessment of instrument behaviour trends, modifications to system in hand, general opinions relating to reliability.

Since completing our first analysis in June practically all the operators concerned have replied and whilst the most recent contributions give us no cause to modify or change the conclusions drawn before, certain aspects have been re-emphasized and, partly from the returns and partly from discussions with reactor operators, there are certain additional comments which can be made.

It is clear that this problem of instrumentation indicating that the reactor or sections of the reactor or test loops are operating in an unsatisfactory way, when in fact there is no reason for concern, is a very real one and no individual organization has yet solved it. This is demonstrated by the fact that almost invariably the number of actual shut-downs that have been prompted by spurious information are considerably in excess of those required for the safety of the equipment. A quite typical figure is that of a total of 50 unplanned shut-downs in the course of a year 40 resulted from spurious information or an involuntary action on the part of the operator.

The Human Element

The human element in reactor operation is one of the most difficult to analyse and it is a field in which exact research and precise solutions are almost impossible to evolve. Even if the reactor is on automatic operation the operator will be responsible for all unusual actions and whereas the temptation to assume that, say, a single channel showing improper operation is faulty, it is much more important that danger signals should not be ignored. As a result, the state of nerves of the operator is likely to be of importance; but, even if these are sound and his judgment correct there is always the opportunity for misinterpreting instructions or simply for accidentally pressing the wrong button. It is easy when planning control rooms to give too little attention to aspects such as these.

Human frailty is a big factor in the maintenance of equipment, also, but proper inspection procedures following maintenance (conducted in an atmosphere of calm) should prove completely effective. What is more difficult to control is running maintenance—the adjustment, for example, of trip levels undertaken while the reactor is in operation. This has given rise in several instances to spurious shut-down and it is a practice that should be avoided if at all possible. There is more reason for such adjustments to be made with research reactors where conditions are continually varying than with power reactors, but even after the commissioning period one can envisage situations in which supervisory staff would like to alter the balance between normal and trip conditions. Reflection that such action might cost, say, £20,000 (a not unreasonable sum for a shut-down on a power reactor) should suffice to prohibit the practice.

We have mentioned previously that there was evidence to suggest that the more complex materials testing reactors, although containing greater safeguards than the simpler research reactors, had a better record of shut-down behaviour. We are not able to make any precise evaluation but the figures returned do suggest that the number of spurious signals taken overall is very similar on the two different types of plant. We should hasten to state that this is almost entirely a subjective appreciation due to the different interpretations based on the meanings of the questions but it would seem to indicate that, quite independently, designers and operators have come to accept the same order of nuisance value. This would lead to the proposition that if the same effort had been put into the design of the small reactors as has been put into the big reactors a much better record could have been obtained, and also that if a uniformly high standard had been adopted through the big reactors they, too, would have a better record. We do not put this forward as a fully substantiated conclusion but it is interesting to speculate whether indeed we are subconsciously setting out sights at a certain nuisance level and if we raise these there would be an improvement in results.

The disturbing feature of the analysis is the number of spurious signals that are observed whose cause cannot be determined, i.e. faults that have cleared of their own accord before or during maintenance or faults arising from outside stimuli which have then been removed. There is no way of distinguishing between the two types but steps can be taken to reduce the number arising from outside influences as these must be either mechanical or electrical, and it may well be that they form the majority of the total number.

It is probable that we over-emphasized in our previous analysis the breakdown aspects of power supplies and neglected the equally (and possibly more) important aspect of variations and surges in them. The designer can do much in the instruments themselves to make them capable of operating under varying conditions of voltage and frequency, and also render them insensitive to surges. Whilst the former may form part of the basic instrument specification and feature in the tests applied, it is rare that surge sensitivity is given much consideration, yet its addition to a test procedure would not be difficult. Where it is almost impossible to protect against mains interference in the instrument units, then some form of surge suppression must be instituted in the main supply.

Too little attention has also been paid to the effects of mechanical jolting and vibration. Although these are not normally features of reactor control rooms, where an almost clinical atmosphere is maintained, they cannot be excluded completely. For example, when a unit is changed in a rack it may be necessary to use a certain amount of force, and in any case one cannot guarantee that careless handling will not result in a fair amount of "knocking about." Recorders with built-in trip contacts can be particularly sensitive to this form of treatment and it would seem reasonable to insist on test procedures not only on individual units but also for racks of units being subjected to mechanical shock in order to assess their sensitivity.

Raising the Standard

Unfortunately, however valid such general comments may be there is none the less a great variety in the nature of the individual spurious signals, but we feel that only by discussing these in the open can a progressive improvement in the general standard be achieved. Some fault may be quite specific to the reactor concerned and the likelihood of its arising in other installations small, but at the same time one reactor designer may have encountered trouble in a particular quarter and cured it whilst another designer may not have come across this problem and may at a future date unwittingly build in the original fault. A case in point could be the recorded instance of radiation damage to magnet insulation which gave rise to much trouble in one particular plant, but which could not at the present time arise in many other installations. On the other hand, whilst we in our demerit tables in June quoted d.c. amplifiers as having the greatest liability to fault conditions, we note that one reactor operator records no troubles from this quarter in his most recent installations, whereas in an earlier installation they figured prominently. This would indicate a very positive step forward in either design or operational practice. We trust, therefore, that when we repeat this experiment operators will allow us to publish, where appropriate, the records of their plant without reservation.

Research Reactor Fault Analysis

A scheme utilizing a punched card data processing system is envisaged in this article. In this way information on any type of fault can be recorded (and subsequently located) quickly and the system would also provide a common base for classifying fault information.

By J. C. MOORE, B.Sc. (Eng.), A.M.I.E.E., A.M.I.Mech.E.
(*Research Reactors Division, AERE, Harwell.*)

AT AERE, Harwell, a scheme has been evolved for recording and analysing the main features of reported faults affecting the operation of research reactors. The important features of any fault are distinguished by means of codes signifying Plant Type, Fault Type, Fault Importance and finally, a Specific Code notifying a limited variety of additional information about the fault for use of analysing officers.

It is hoped that its adoption will result in the following advantages:

(a) As information recorded in the manner described can be quickly retrieved, the necessity for prodigious feats of memory with respect to fault history can be obviated.

(b) Information can be presented quickly in a variety of chosen orders and histogram presentation of any past fault history can be rapidly established.

(c) Use of records by "outsiders" or other information seekers (e.g., designers or operators of other reactor systems) will be easy.

(d) Effective maintenance programmes can be directed more easily.

(e) A common base can be established for classification of fault information.

Philosophy Behind the Scheme

The system as outlined is well suited to the storage of coded and classified information which initially comes to reviewing officers in information "bits." Unless the information "bits" are reduced to a common denominator their significance, if later included in verbal reports, may tend to be masked. Verbal reports are not only lengthy to compile but very lengthy to search and if the records extend over a period of years, a full search is almost impossible to do. Certainly it is generally only after they have been carried out that one can see whether the results justify the effort or not.

Reports are usually written from a particular view-point. Examination often prompts a variety of questions which demand considerable readjustment or "sorting" of the original report information. It is essential, therefore, that the basic information can be selected quickly into various patterns of presentation. Statistical information on events which occur in a random-incidence or time-series pattern, or which possesses various degrees of correlation with other basic causes (as is usual with plant-fault occurrence) should be capable of a high degree of "information pattern" adjustment. The present scheme lends itself readily to such practice.

It is hoped that as a result of experience in its operation common factor information relating to research reactors of widely differing characteristics will quickly emerge. Normally few people are in a position to appreciate such common factors. Accurately coded and retrieved information requested with only a limited requirement in mind, will give rise to the request for correlation or comparison of this information with other reactor systems, from which the common factors become apparent. Often with report presentation on matter of considerable detail, readers fail to obtain a bird's-eye view of significant implications, especially when they do not have first-hand experience of the subject considered. It is hoped that by means of chart presentation of significant plant-fault information the appreciation of fault effects in particular plants may quickly be established.

Brief Description of the System

Fault returns on all reactors at Harwell are submitted daily and are arranged as in Fig. 1. Four fault-characteristic codes (see Fig. 2) are then allotted as follows:

Plant Type Code

The faulty plant is identified in the Plant Type chart (shown in Figs. 3A and 3B). This chart sub-divides all the plant in a logical sequence, allocating a code number at each stage on a decimal classification principle. Plant at fault is identified into a category to obtain this code.

Although it may appear at first sight that equipment type is the fundamental sequence of the Plant Type chart it is important to realize that it is the functional aspect of the equipment which is basically considered. This is of considerable importance in any subsequent cross-comparison between reactors.

FIGURE 1

Reactor	Fault No.	Date	Fault Description	Fault Clearance	Plant Type Code	Fault Type Code	Fault Importance Code	"Specific" Code
DIDO	1348		Manual Valve on Scrubber unit showing "open" and "shut" in Control Room.	Limit Switch sticking.				
DIDO	1349		Leak on rubber connection to cell on Oxygen Unit.	All joints remade.				
DIDO	1350		Valve on acid filling line—bulk storage. Extremely stiff to operate.					
DIDO	1351		Water leak from space heater in Reactor basement.	Joints tightened up.				
DIDO	1352		Fast neutron Head Amplifier No. 19 showing warning, no reading on meter or amplifier.	Rectifier changed.				
DIDO	1353		Thermocouple on Nitrogen side of 1B drier is not reading correct temp.	Thermocouple tail broken; Remade.				
DIDO	1354		No speak on public amplifier in reactor shell.	Fault cleared while investigating.				
DIDO	1355		Crane operating lamp U/S.	Lamp on order.				
DIDO	1356		C4 Temperature Meter. Trip lamp does not light.	Bulb changed.				
DIDO	1357		No. 8 cooling tower rubbing on mounting pedestal.	Fouling greaser cleared.				

FIGURE 2

Fault Description	Fault Clearance	Date	Fault No.	Plant Type Code	Fault Type Code	Fault Importance Code	"Specific" Code	Reactor
Manual valve on scrubber unit showing "open" and "shut" in Control Room.	Limit switch sticking.		1348	511122	111	29	—	DIDO
Leak on rubber connection to cell on Oxygen Unit.	All joints remade.		1349	5122531	331	126	—	DIDO
Valve on acid filling line—bulk storage. Extremely stiff to operate.	Awaiting Operations to drain system. Valve as yet unexamined.		1350	5122242	—	25	44	DIDO
Water leak from space heater in Reactor basement.	Joints tightened up.		1351	512332	321	25	—	DIDO
Fast neutron Head Amplifier No. 19 showing warning—no reading on meter or amplifier.	Rectifier changed.		1352	512221	132	124	—	DIDO
Thermocouple on Nitrogen side of 1B drier is not reading correct temp.	Thermocouple tail broken; Remade.		1353	511347	26	28	—	DIDO
No speak on public amplifier in reactor shell.	Fault cleared while investigating.		1354	51141	—	124	2	DIDO
Crane operating lamp U/S.	Lamp on order.		1355	511123	—	124	45	DIDO
C4 Temperature Meter. Trip lamp does not light.	Bulb changed.		1356	511341	133	27	—	DIDO
No. 8 cooling tower rubbing on mounting pedestal.	Fouling greaser cleared.		1357	512222	311	25	—	DIDO

Fault Type Code

The type of fault is coded similarly but is identified in the Fault Type Chart (Fig. 4). In this case it is the engineering characteristic of the fault which is identified and not the type of plant on which it has occurred.

Fault Importance Code

The basic idea embodied in this code recognizes that one is only concerned about faults because either they are unsafe, or they are a nuisance. The stress on safety is well understood by all and the only division of emphasis is to distinguish between those which actually produced a dangerous state and those which potentially could have given rise to this condition. It is important to include such sub-division in this safety field. Indeed it is hoped that the present scheme will throw new light on, and give quantitative information concerning, the potential hazard from faults, and the weight that must be placed on this in general reactor philosophies, as also on the "coincident-fault" hazard, which, while the subject of much current reactor safety thinking, is nevertheless unsupported as yet by significant quantitative information.

Examples of faults of nuisance value only, but of varying importance, are reactor trips, faults giving rise to prevention of reactor start-up and high maintenance attention on plant utilized (often a necessity in plant in research and experimenal fields which has a high prototype component); and faults giving rise to operating staff gaining wrong information about the plant (i.e., incorrectly displayed or recorded information). In devising this numerical code, opportunity has been taken to align it with the current codings used in the Research Reactors Division for reactor defects (viz., unscheduled shut-downs or unusual occurrences). This coding (derived from Plant Engineering Group classification in another field) is related to the present Fault Importance code as shown in Table 1. The definition of the various categories of the Fault Importance code are given in Table 2.

TABLE 1

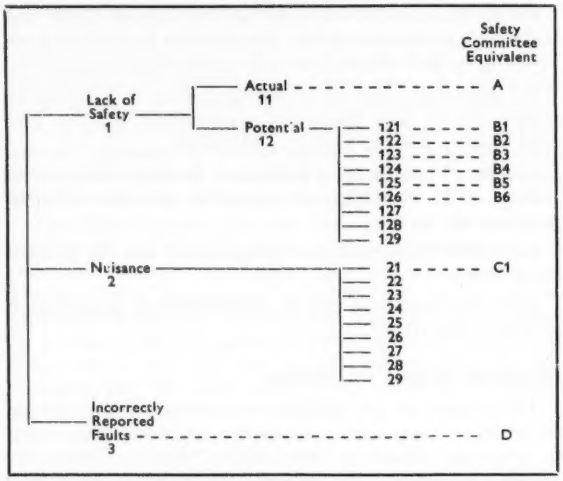


TABLE 2

Fault Importance Code	Safety Committee Equivalent	Definition	Fault Importance Code	Safety Committee Equivalent	Definition
11	A	Faults actually invalidating a reactor safety feature (N.B. Magnitude of effect is here unconsidered).	21	C1	Producing no safety implications when considered separately but when taken in conjunction with other similar defects raise doubt on the system, whether mechanical or human.
121	B1	Faulty operation of any trip initiating equipment (failure to operate or spurious operation are here considered equal).	221	—	Trip of reactor from power.
122	B2	Faults affecting the correct functioning of other important plant equipment.	222	—	Trip of reactor at shut-down.
123	B3	Incorrect operation of important plant equipment (mainly incorrect adjustment of plant trip levels).	23	—	Prevention of reactor start-up.
124	B4	Producing a personnel hazard (e.g. mechanical failure of a rig releasing fission products to an external circuit).	24	—	Design defects or imperfections.
125	B5	Mis-intended operation of equipment by human operator (e.g. pressing wrong control buttons; bad synchronizing actions, etc.).	25	—	Giving rise to high maintenance attention.
126	B6	Producing a condition with safety implications not covered in previous categories.	26	—	Incorrect displayed information—Recorders.
127 to 129	—	Unallotted.	27	—	Incorrect displayed information—Electronic Instruments.
			28	—	Incorrect displayed information—All other reactor displays.
			29	—	Miscellaneous nuisance defects.
			3	D	Incorrect reportings.

Specific Code

It is essential that complete fault clearance action always takes place. In a visually presented fault-card system one may imagine the use of a series of "flags" or labels on each card to represent types of, stages in, or other aspects of, fault clearance action.

The specific code enables a fault classifying officer to keep before him many aspects other than plant and fault types and importance, and thus ensure complete and satisfactory fault clearance action.

The Specific code and its significance are shown in Table 3.

Typical Operation of the System

The coded information suitably columnized is punched on to standard 80-column I.C. and T. Ltd. (Hollerith) cards.

Sections (a), (b) and (c) of Table 4 show:—

(a) The original tabulation of the initial coded information. It will be noted that all codes are random.

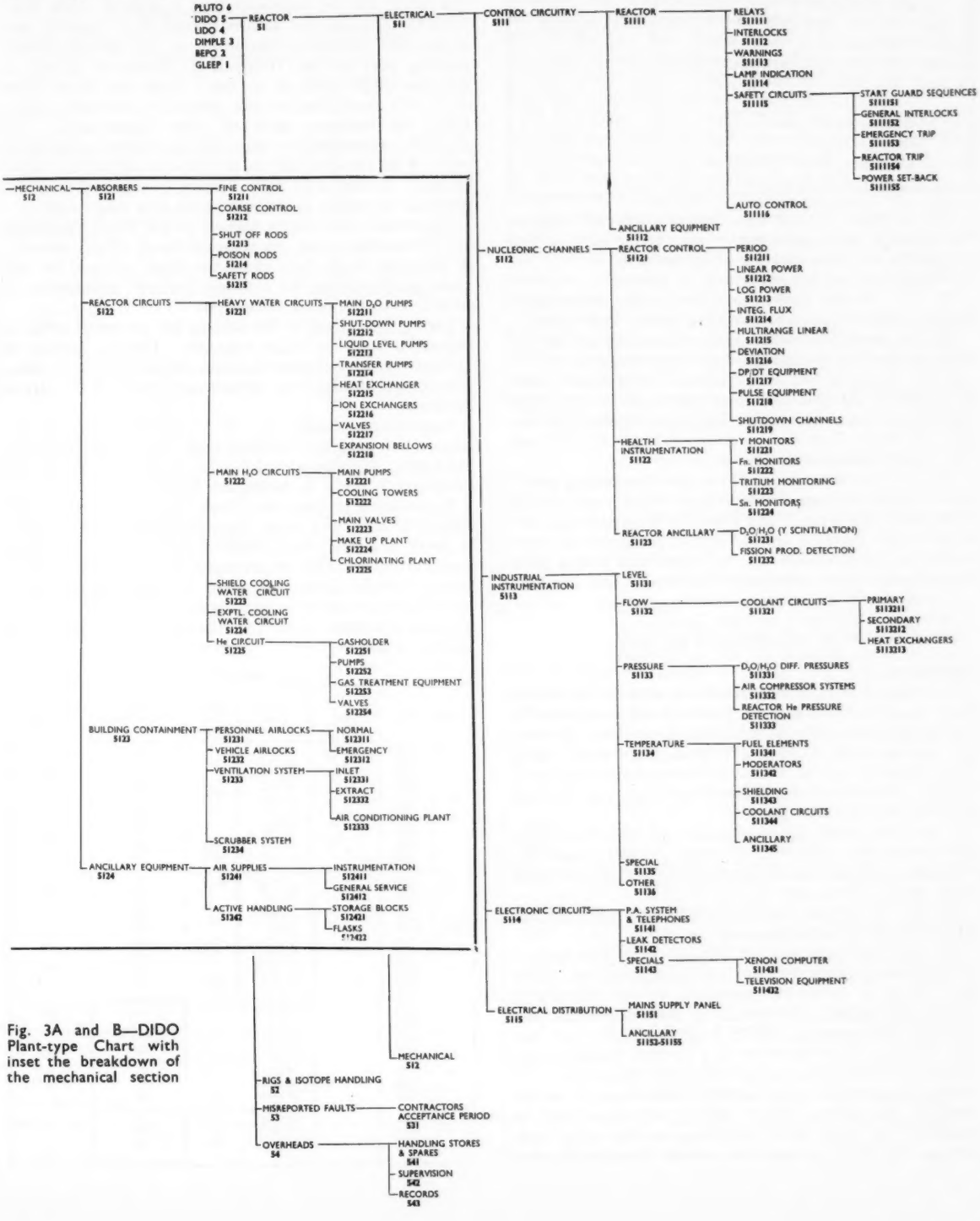
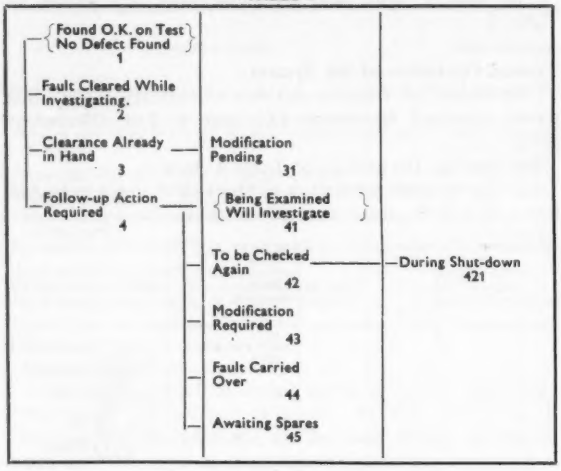


Fig. 3A and B—DIDO Plant-type Chart with inset the breakdown of the mechanical section

TABLE 3



With a mass of fault data, before particular analyses are required or suggest themselves, preliminary sorting operations and tabulation are often desirable.

Sections (b) and (c) are typical of these.

(b) This section shows the initial coded information machine sorted (and tabulated) into Plant Type order.

(c) The same information used in Sections (a) and (b) is shown machine sorted into Fault Importance order.

It will be noted (see Section (c) of Table 4) for faults Nos. 1357, 1350 and 1351 that within the "25" Fault Importance group, both Fault Type (i.e. numbers 311 and 321) and Plant Type (i.e., numbers 512222, 5122242 and 512332) are in the correct order.

This is a valuable feature of the machine sorting operations. Such orderings are dependent entirely only on the order (i.e., Plant Type, Fault Type, Fault Importance, etc.) in which the numbers are sorted and are produced automatically. Considerable help and suggestion is thus given automatically to the subsequent analysis of fault data.

Typical speeds of machine operations are:—

Sorting—36,000 cards per hour (approx.).

Tabulating—5,000 to 6,000 cards per hour.

Experience

Information so far sorted into the system is that derived from the Maintenance Fault Defect Book completed by Operating Staff in all reactor control rooms. Also information coming daily from Maintenance Supervisor's Daily Work Returns and the Division's safety committee forms (Reactor Defects—Unscheduled Shut-downs and Unusual Occurrences) has been added.

It has been found that if necessary the system can cope with tremendous refinement of detail. In this respect two criticisms might be made from study of the Plant and Fault Type charts. These are:

(a) That the scheme does not include every plant or fault type which may exist in reactors.

(b) That the charts are over-detailed in certain areas.

To both comments the same answer applies, that, rather than being a theoretical approach to an all-inclusive scheme, the skeleton framework of both charts has been built up from practical AERE fault experience, and that improvement of the charts by way of more complete subdivision or combination of over-detailed groups will only become apparent as more statistical information is assimilated by the system. Often such modifications may be possible with only minor alteration to the basic card, but at the worst a machine search through the area to be modified will produce the cards to be recoded.

Again translation of selected information from one card to another is often an automatic machine function taking place extremely rapidly. After modification, cards can be placed back into the scheme carrying their new information without disturbance to the scheme as a whole. Once basic cards are punched, many other processes, e.g., card-copying, tabulating, sorting, gang-sorting, alteration of coded information, etc., can be made an extremely rapid automatic machine process.

It must not be supposed that a lengthy code (e.g., 5122533—meaning the Recombination Unit forming part of the Gas Treatment Equipment on the Helium Circuit forming part of the Mechanical Circuits in DIDO) is correspondingly difficult to use. From the Plant Type chart it is established in one operation and then copied. From the machine point of view "gang-sorting" on 5122533 (i.e., sorting for the complete number rather than parts of the number) can be as fast as a sort on the initial figure 5. In fact a 16 digit code (or 16 digits of information) can be sorted in the same time as a single digit.

Apart from the reactor integer in the Plant Type code the information codes are common to all AERE reactors. A universal Plant Type chart has been achieved so that consequently sorting of common features throughout all AERE reactors can be carried out.

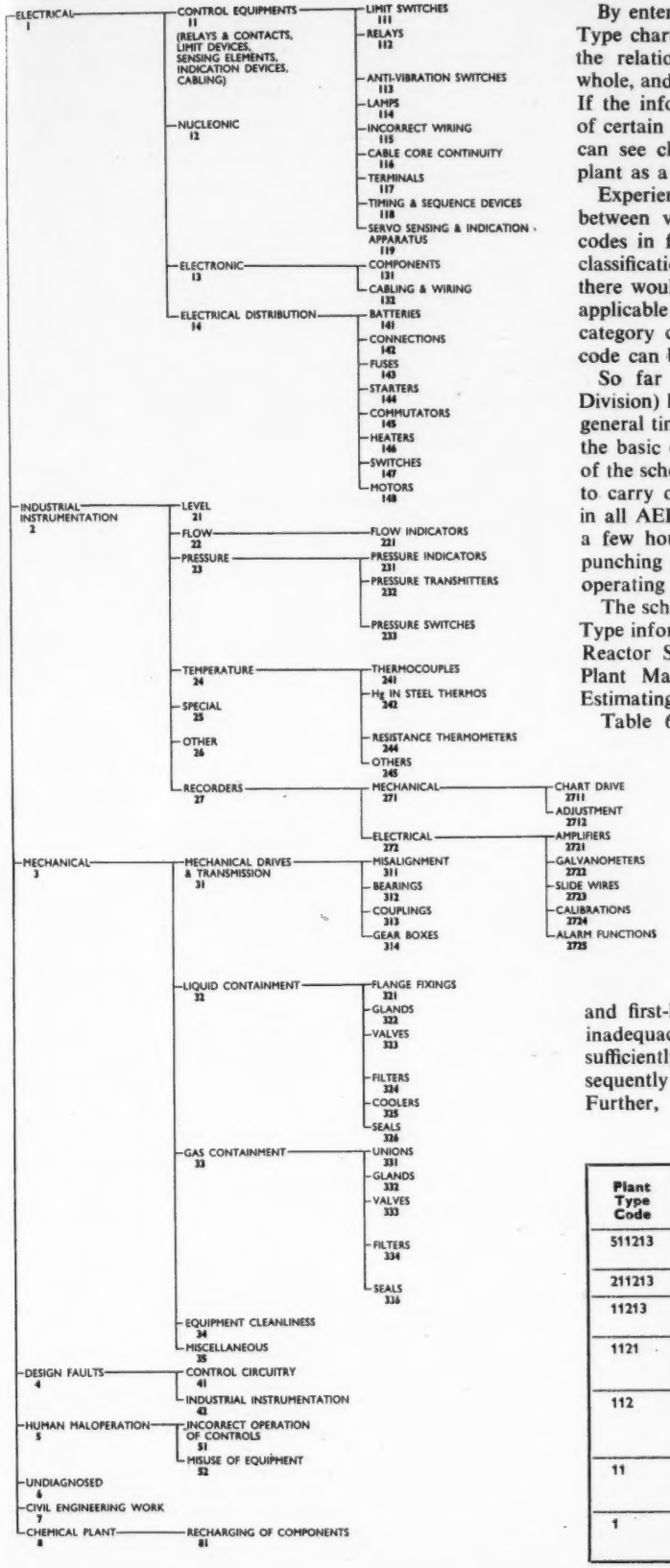
Sorting operations in the scheme are normally series or sequential sorts in single columns. That is, sorting of numbers in an individual column. If one resorts to gang-sorting, combination or coincidence information can be retrieved.

Combination faults, e.g., of a certain importance on stated plant and of a specific basic cause, can easily be produced. If necessary this information can be directly presented in detail or histogram form.

Coincidence sorting (say Plant Type information with respect to date, and Fault Type information with respect to date), and final presentation of the cards in date order would throw first light on the possibility of coincident parameters between cause and effect in reactor faults. It is hoped by this means to investigate quantitatively the two or more coincident faults hypothesis at present current in reactor circles.

TABLE 4

	Fault No.	Date	Plant Type Code	Fault Type Code	Fault Importance Code	Specific Code
(a)	1348		511122	111	29	
	1349		5122531	331	126	
	1350		5122242		25	44
	1351		512332	321	25	
	1352		512221	132	124	
	1353		511347	26	28	
	1354		51141		124	2
	1355		511123		124	45
	1356		511341	133	27	
	1357		512222	311	25	
(b)	1348		511122	111	29	
	1355		511123		124	45
	1356		511341	133	27	
	1353		511347	26	28	
	1354		51141		124	2
	1352		512221	132	124	
	1357		512222	311	25	
	1350		5122242		25	44
	1349		5122531	331	126	
	1351		512332	321	25	
(c)	1355		511123		124	45
	1354		51141		124	2
	1352		512221	132	124	
	1349		5122531	331	126	
	1357		512222	311	25	44
	1350		5122242		25	
	1351		512332	321	25	
	1356		511341	133	27	
	1353		511347	26	28	
	1348		511122	111	29	



(Left) Fig. 4.—Fault-type code for DIDO.

By entering sorted information on to Plant and/or Fault Type charts, a reviewer can be given a clear indication of the relationship of this information to the plant as a whole, and therefore a greater appreciation of likely effects. If the information on charts is selected initially as being of certain safety or fault nuisance importance the reviewer can see clearly the differentiation of these effects in the plant as a whole.

Experience indicates that good general agreement occurs between various grades of staff called upon to use the codes in fault classification. It would appear that if all classification was not done by the most senior engineer there would be a fair chance of common standards being applicable in code determination. Allocation of the special category codes, e.g., Fault Importance code and Specific code can be the prerogative of a senior engineer.

So far Plant Engineering Group (Research Reactors Division) have timed all their operations on the cards. The general time of allotting all codes to cards and carrying out the basic card punching even in the present training stage of the scheme is less than one minute per fault. The ability to carry out all coding and punching on faults occurring in all AERE reactors for a month in something less than a few hours is a feature to be appreciated. Training in punching principles is a simple matter, and costs of operating the scheme are comparatively low.

The scheme is being interlocked with other essential Plant Type information and management control operations, e.g., Reactor Shut-down or Unusual Occurrence Information, Plant Maintenance Scheduling and Man-hours Costing, Estimating and Planning Information, Spares Holdings.

Table 6 tabulates typical information carried by the series of cards in the first three of the above groups and also the Fault Analysis card series

(Below) Table 5.—Example of result of sorting on codings of six to one digits.

Conclusion

In any situation of this complexity it often transpires that the full effectiveness of memory and first-hand knowledge of events is debilitated by the inadequacy often experienced in recording these events sufficiently quickly and accurately in order to serve subsequently as a fund of experience on which to direct action. Further, the marshalling of such information later is

TABLE 5

Plant Type Code	Significance
511213	Fault on *LOG POWER* channel part of *NUCLEONIC, REACTOR CONTROL CHANNEL* in *DIDO*.
211213	As above but for *BEPO* reactor.
11213	*LOG POWER, NUCLEONIC, REACTOR CONTROL* channel information in *all* reactors.
1121	*NUCLEONIC, REACTOR CONTROL* information in *all* reactors (i.e. including for instance "Linear Power," "Period," "Integrated Flux," etc.).
112	Any *NUCLEONIC* information in *all* reactors (i.e. including the groups "Health Instrumentation"—not connected with "Reactor Control"—and "Reactor Ancillary" e.g. D_2O in H_2O scintillation counting apparatus).
11	Any *ELECTRICAL* information in *all* reactors (i.e. including "Electrical Distribution," "Control Circuitry," "Industrial Instrumentation," etc., but excluding "Mechanical" troubles).
1	"*REACTOR*" information (as distinct from "Rig" information) in *all* reactors.

difficult; correct opinions may be held concerning any situation but these are often difficult to sustain against challenge and are not often supported by statistical weighting of the various events.

The system outlined appears to be fulfilling the hopes expected of it in its ease of use, especially with respect to its retention of detail in the recording of past events. Once basic data has been recorded the system has proved extremely flexible in its ability to produce easily any required data. From day to day use it is abundantly clear that, providing a sufficiently comprehensive structure forms the basis of the scheme, more and more uses continually arise to which the system can be moulded. Certainly, as yet, the possibilities developing from the system are by no means exhausted.

The author has been fortunate in having available the use of Hollerith machines by means of which cards can be processed. In the author's case this conditioned to a large extent the type of punched-card which was finally adopted. However, serious consideration had been given to many other card systems prior to a final decision, and the conclusion was reached that although particular preferences might exert themselves in the final choice, the system as outlined could be operated with, and certainly did not depend on, the use of any particular card system.

An acknowledgement is made, with thanks, to Mr. R. F. Bearman in Plant Engineering Group (R.R.D.) Technical Records Office, Harwell who has willingly undertaken much of the work involved in the initial setting up of the scheme.

TABLE 6

Item	Used on :—			
	Unscheduled Shutdown Cards	Fault Analysis Cards	Man-hours Costing Cards	Maintenance Scheduling Cards
Date	X	X	X	
Card series serial No.	X	X	X	X
Hours since last shutdown	X			
Duration of shutdown	X			
Reactor state at shutdown	X			
Type of shutdown effected (e.g. Manual, Auto, etc.)	X			
Reactor code	X	X	X	X
Fault number		X		
Plant type	X	X	X	X
Fault type	X	X		
Fault importance	X	X		
Specific code	X	X		
Type of work carried out (e.g. Maintenance, Modification, etc.)			X	
Hours consumed			X	
Plant category				X
Plant item				X
Coded maintenance scheduling information				X

British Exhibits at Stockholm

FIFTEEN U.K. concerns, in addition to the AEA, participate in the Fifth International Instruments and Measurements Conference and Exhibition being held in Stockholm, September 13-15. The conference is organized by the Royal Swedish Academy of Engineering Sciences and the Swedish Association of Technical Physicists and 26 papers from the U.K. have been accepted. 14 of these are contributed by the AEA and include, "Experience of Instrument Maintenance at Calder Hall," by R. C. Vincent (production group) and "Instrumentation of the Dounreay Fastbreeder Reactor," by R. Smart (D. and E. Group). A paper on "Applications of Transistor Techniques in Reactor Instrumentation" is to be presented by G. G. Ballard of Elliott Nucleonics.

Included in the **AEA's** exhibit of advanced nucleonic instruments is a plutonium-in-air alarm monitor capable of giving a rapid warning of the release of plutonium into the atmosphere by continuously sampling air for plutonium alpha activity. Plutonium dust particles are impacted on to a zinc sulphide coated film which is measured continuously with an alpha scintillation counter. Particles of about 1 micron are collected and the discrimination efficiency in favour of larger particles is about ten to one. Sampling is carried out for preset periods and the integral count recorded at the end of each period. Sampling rate is 18-20 cu. ft of air per minute, and the control and alarm unit consists of four main circuits, timing, scaling, alarm trip, and EHT and HT power supplies.

ULTRA temperature trip amplifier.

The **Plessey Nucleonics** stand is entirely devoted to a display of burst fuel element detection systems, health monitors and other types of nucleonic instruments. A working model of their latest Mk. III precipitator is also shown.

Pluggable resistors and capacitors are shown by **Erie Resistor.** These components are specially designed to ensure that the component is firmly installed at a constant distance from a printed board after mounting.

A scale model of the Berkeley High Activity Laboratory designed by **Hobson** is displayed by this company. The laboratory is designed to receive highly radioactive irradiated fuel elements from CEGB power stations, remove and strip off the enclosing can and then carry out measurements and take X-ray photographs of the elements. A model of the coarse control arm showing the operation of the coarse control shut-off system as used on the DIDO and PLUTO reactors is also shown.

GEC and **Simon Carves** have an interesting exhibit with particular stress on instrumentation and control equipment for nuclear installations. Principal exhibits include burst cartridge detection equipment for gas-cooled or water-cooled reactors, control position indication equipment, apparatus for the detection and location of leaks in steam raising unit tubes and digital data-handling equipment.

Temperature trip amplifiers for reactor safety systems are the main feature of the **Ultra Holding** stand.

U.K. exhibitors are: **U.K.AEA, Ether Langham Thompson, General Electric, General Radiological, H. M. Hobson, Plessey International, Solatron Electronic, Temple Press** in association with **Heywood** and **George Newnes, 20th Century Electronics, Ultra Electronics, Associated Electrical Industrial, Cannon Electric, Colvern, Erie Resistor, A. H. Hunt** and **Texas Instruments.** The last six are exhibiting as the **English Component Group.**

Towards Greater Reliability

Some Succinct Comments on the Choice of Instruments

By R. D. TROTTER and F. T. LAW
(*Nuclear Plant Design Branch, CEGB*)

STATISTICAL analysis of the sources of instrument faults is difficult to apply partially due to the large number of types of instruments commercially available, and partially because of the very varied nature of the faults which occur. Moreover, both components and instruments are subjected to a wide range of operating conditions. This article outlines methods of analysis aimed at ensuring the purchase of reliable equipment.

The choice of an instrument for a specific application can conveniently be considered under the following six headings: —

(1) Performance specification;
(2) Choice of components;
(3) Method of construction;
(4) Impartial assessment of instruments available;
(5) Factory test specification for the instrument;
(6) Maintenance.

It is important when considering the choice of an instrument that the complete function that the instrument is to carry out should be assessed, together with the conditions under which the instruments will have to operate. Surprisingly, manufacturers of instruments often do not quote a complete specification and it is often difficult to ascertain what ability an instrument has to tolerate supply variations, and what the effects of variation of such factors as ambient temperature will have on the instrument performance.

The recent article in *Nuclear Engineering* (p. 241, June, 1960) on the sources of instrument faults makes very interesting reading, and will prove most useful if the analysis of faults and their causes can eventually be carried through to identify these features in greater detail (see page 383 this issue). For instance the apparent criticism of relays is not directly useful unless information is available on the kinds of relay which are found to be faulty and the types which are found to have a good performance, the relative numbers of each and, most important, the conditions under which the relays were operating. Here again, the wide variety of components and operating conditions will make it difficult to obtain a reliable statistical sample under any given operating condition. Furthermore, new kinds of instruments are constantly being introduced which cannot be compared directly with earlier types and some way of predicting reliability factors from previous experience of the components used would be a great help. The use of components that have been approved by the Radio Component Standardization Committee of the Ministry of Aviation gives some indication of components which are suitable for certain applications. Unfortunately the process of approval takes considerable time, which means that the latest component which would probably be encountered in modern instrument design is not available from the R.C.S.C. approval lists. Therefore, when considering the choice of component, the user must endeavour to make up his own mind as to the suitability of a new product. To rely only on the use of the older components of which the quality has been established is to pass the responsibility on to other users—a cowardly policy.

Some simplification may be achieved by reducing the number of different components. A good example of this is the choice of thermionic valves. If vigorous efforts are made, the CV4000 series of special reliability valves can be substituted for most valves in industrial instruments and the designers of new instruments can be encouraged to restrict their choice to this type. Not only is this series of valves likely to prove more reliable because of the extra care in testing them (the soak test given to each valve in this series helps to eliminate early failure of instruments), but the reduction in the number of valves which have to be stored as spares is also well worth while. The most important feature of this policy, however, is that where certain valves in this limited range prove unsuitable for some particular application, then the smaller number of types in use makes this feature more quickly recognized, and easier to cure.

If it is felt that policies such as this applied to all components will inevitably put up the cost of instruments, there are two points which can be made.

(1) If these practices became widespread throughout industrial users, then the exceptional quality valve of today will become the commonplace of tomorrow and the eventual cost of instruments should not be greatly affected.

(2) For all process industries the cost of instruments is generally insignificant when compared with the losses incurred when plant is out of action due to instrument failures.

Not only must reliable components be used, but these must also be assembled in such a fashion that the reliability of the whole instrument is as good as possible. The Services form the largest users of electronic equipment and over the years they have evolved codes of practice for determining constructional procedure. It may well be that many industrial users will feel that these codes of practice could easily be adopted for their own purposes. If this process became widespread, a uniform policy of design, manufacture, and use of instruments, would gradually evolve which would probably mean that the best construction principles would be demanded by the majority of instrument users. This in turn might mean a substantial reduction in the cost of well-designed instruments.

Another contribution to the choice of reliable instruments can be made by insisting on having the first instrument of any type assessed by actual bench tests. In this connection it may be of interest to mention the assessment of instruments which is being carried out by the British Scientific Research Association on some of the instruments purchased for the CEGB. The assessment report on each instrument is divided into three sections. The first considers the components used, the layout of these components and the general methods of construction. The second is a study of the detailed performance of the instrument to ascertain whether the manufacturer's claims of range, accuracy, etc., are achieved and also whether these factors are unduly influenced by variations in supply voltage and frequency. Any special tests specified for instruments being used for peculiar applications are included in this

section. The third section covers environmental testing over a range of temperature and humidity, etc. In the authors' view it is most important that an assessment of this nature should be carried out in an impartial manner and that the reports should consist of a comparison to codes of practice for construction and to approved component lists. The reports should be a statement of observed facts and performance, and not an expression of opinion. The purchaser is then free to apply his own judgment in asking for any modifications to the instrument which he may feel are necessary, if he eventually decides to purchase. He can apply this judgment with proper regard to commercial considerations. The manufacturers will also know that the reports issued are on a well defined and impartial basis. This process is often welcomed enthusiastically by the manufacturers, but again if such reports were available to a wider circle of subscribers, the cost of assessment (a few hundred pounds for a complex instrument) could be reduced.

We consider it appropriate during this assessment, to insist on determining the performance of instruments under wide variations in the voltage and frequency of the power supply. Tests of this nature eliminate circuits which are near to failing at normal power supply voltage and frequency. They should be applied to instruments whether or not they are in practice supplied from very special supply systems, which may be closely controlled. It is necessary to limit the time spent on test at extreme combinations of voltage and frequency in order not to unduly influence the thermal ratings of some components. For instruments used in protection circuits, e.g., reactor safety circuits, it may be considered prudent to apply the limits of voltage and frequency in all combinations and to apply these changes as short-term transients. This is particularly true for nuclear power station safety circuits, for a loss of supply from the generating station following on distortions to the normal grid system through other causes is particularly unacceptable. For normal indicating instruments, however, it may well be said that frequency variations should be applied at normal supply voltage and the voltage variations should be applied at normal frequency. In general, the variations in frequency occur as a result of trouble on the grid supply system, whereas voltage variations may well be caused by more local faults and these two causes will not often coincide. Also the tolerances which are applied to the effects of off-normal supply must be related to the importance of the instrument duty and the accuracy that is required from the instrument by operating considerations.

The tests carried out under varying conditions of humidity and temperature should have a range slightly greater than that of the working conditions of the instrument. The ambient temperature appropriate may be influenced by other working equipment perhaps in the same cubicles or apparatus rooms. A wide range of conditions may not be encountered whilst the instrument is in service but may possibly be encountered during transit or storage. The tests will also detect components which are running near to the limit of their rating. Particular care must be taken in specifying the ambient temperature conditions for transistorized equipment. This is often protected against excess temperatures by locating the equipment in air-conditioned rooms or cubicles in which case care must be taken that the whole of the transistorized equipment (which may be a complete reactor protection system) is not dependent upon one air-conditioning unit which may have a low reliability.

Having carried out assessment work, it is then necessary to be sure that subsequent production instruments will achieve the same performance as the model which has been assessed. In addition to checking that components are unchanged the manufacturer's test and inspection procedures require examination; one can feel confident that instruments of a greater reliability will be issued from the factory if a period of soak testing is included in the factory test specification. This soak test should consist of a preliminary rough setting up prior to soaking and a detailed performance check should be carried out after soaking. If any failure occurs during the soak test, the faulty component should be replaced and the procedure repeated.

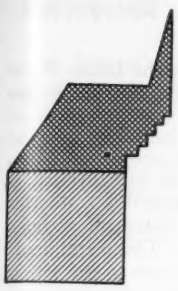
It must be admitted that it is not possible at the moment to purchase perfect units of electronic equipment. Therefore although plugs and sockets generally introduce their own range of faults, it is necessary to engineer many systems on the basis of easily replaceable plug-in units. It is to be hoped that this state of affairs will gradually cease, particularly as reliability is constantly improving and may well take a big step forward with the introduction of all-solid-state circuits.

At the present time, however, some circuits have been laid out with these features in mind, as the availability of the plant may to some extent depend upon the speed with which faulty instruments can be replaced. With this in mind, it may well pay to keep stand-by units on soak in the instrument maintenance workshop.

In the authors' view it does not seem wise to recommend preventive maintenance policies for most types of electronic instruments, as it appears that more harm than good is often done, especially to valve life. Operating tests from simple input feeding circuits are necessary for protection apparatus although this can often also be made to fail to safety. Marginal testing (i.e., operation at suitable reduced power supply voltages) can be applied to give warning of the onset of instrument deterioration. In these circumstances, if maintenance is to follow the principle of leaving units alone until trouble occurs, it becomes very important to engineer any system so that units can be easily replaced.

The instrument maintenance staff need to be backed up by the management by the provision of good maintenance workshop facilities with plenty of space, adequate equipment and a clean atmosphere in which to work, and to store instruments in good conditions. Care should be taken that the staff have sufficient theoretical and practical knowledge to make any necessary repairs to instruments in such a way that the original reliability is maintained. The grade of labour required for the instrument workshop is more akin to the laboratory technician rather than the instrument mechanic. Good records of maintenance experience are necessary if the essential feedback from operating experience to design policy is to be obtained.

In conclusion, therefore, in the authors' view the large users of instruments in the country should try to get together to reduce types of components and valves in use, to pool knowledge on reliability of installed instruments, and to be prepared to pay for high quality instruments. Instrument users should also take a greater interest in the development of new techniques. The British Scientific Instrument Research Association has less than 20% of the members from the user side of the industry. If assessment of instruments is carried out by the users prior to purchase, and they are positive in demanding high standards of construction and performance, then the manufacturers of instruments will be encouraged to offer these not as very specialized requirements, but as standard procedure.



SUPERHEAT AND THE BWR

1—Why and How?

THE desirability of superheat in a steam cycle is so frequently taken for granted that it is with some diffidence that one raises the question of why it is necessary. For the benefit of those without experience in steam work, however, it may be as well to take a brief look at the whys and the wherefores.

Superheating of steam, i.e., raising it above its saturation temperature—or the natural temperature at which it boils at a given pressure—is desirable for several reasons. In the first place, it avoids excessive wetness at the low-pressure end of the turbines, thus cutting down mechanical losses. Secondly, it improves the thermodynamic efficiency due to eliminating the "wetness loss" in each stage. Thirdly—and most important—it gives a very considerable increase in the thermodynamic efficiency of the whole cycle, by increasing the proportion of "usable" heat to the total heat in the steam.

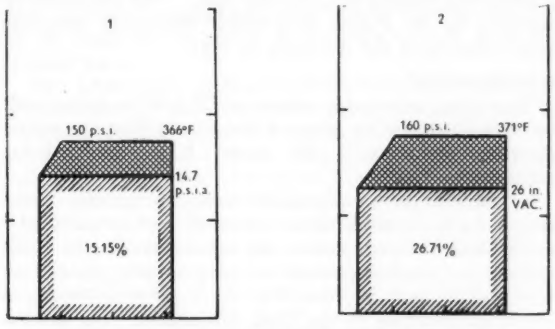
Reduction of Wetness

For expansive working, there is a limit of pressure above which it is not practicable to go, without superheat, because of the wetness of the steam after expansion. A recent paper[1] has shown that to obtain acceptable limits of wetness at the L.P. end, there is no point in generating saturated steam above 50 p.s.i., unless moisture separators are fitted, and their attendant losses accepted. Even with separators, wetness loss will still be high, since separators can only mechanically remove the entrained water; the steam immediately after separation is still "wet" steam, and readily condenses, unlike superheated steam which, behaving like a perfect gas, does not give up its heat so readily.

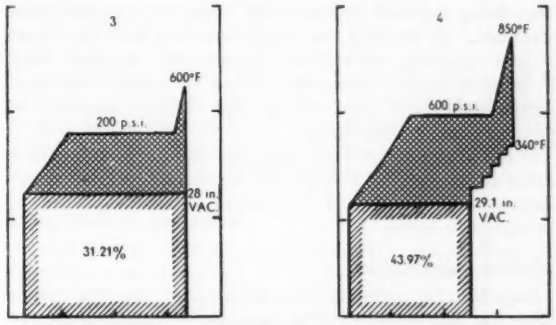
Thermodynamic Efficiency

A very large proportion of the heat in steam is the latent heat of evaporation, which must be supplied to change the state of the water to steam in the first place, and must afterwards be rejected again in condensation, without having been available for doing work, and the lower the conditions of the steam, the higher does this proportion become. It is, perhaps, over-simplifying the position to say that having expended the latent heat in producing the steam, we might as well cram as much "usable" energy into the steam while we have it, but that is, roughly, the position.

The situation may be clarified if we examine some temperature-entropy diagrams due to Pearce[2]. Here the vertical scale is temperature (plotted from absolute zero) and the horizontal scale is heat in B.t.u. The dark shaded area is the "usable" portion of the heat energy; the lower the "unusable" portion.



Temperature-entropy diagrams for saturated steam.
Fig. 1.—(Left) 150 p.s.i., atmospheric exhaust, basic cycle efficiency 15.15%.
Fig. 2.—(Right) 160 p.s.i., 26 in. vacuum, basic cycle efficiency 26.71%.



Temperature-entropy diagrams for superheated steam.
Fig. 3.—(Left) 200 p.s.i., 600°F, basic cycle efficiency 31.21%. Fig. 4.—(right) 600 p.s.i., 850°F, 4-stage feed heating, basic cycle efficiency 43.97%.

Fig. 1 is the cycle diagram for the first turbines installed at Manchester Square in 1895. The steam pressure is 150 p.s.i.g., dry saturated (366°F) and the turbines worked non-condensing, exhausting to atmosphere. The basic efficiency of this cycle is a little more than 15%, which can immediately be improved to over 26% by the use of a condensing cycle (albeit an inefficient one of only 26 in. vacuum) and raising the steam pressure 10 p.s.i. (Fig. 2.)

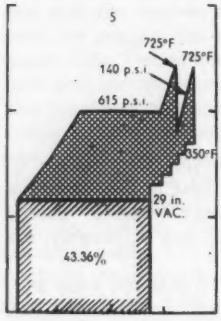
The improvement in working to 200 p.s.i. (sat. temp. approx. 388°F) and superheating to 600°F, as well as exhausting to a 28 in. vacuum, can be seen in Fig. 3, which shows 1919 steam conditions. The basic cycle efficiency is about 31%. Finally, 600 p.s.i. (528°F) steam superheated to 850°F conditions are shown in Fig. 4, which incorporates several stages of feed heating, and has a basic efficiency of nearly 44%.

It must be borne in mind, of course, that basic cycle efficiencies are those theoretically possible, and not practical figures. The actual turbine thermal efficiency of Fig. 4 was about 35%, while the station thermal efficiency, based on units sent out was only about 30%. However, the figures show the improvement obtainable with higher steam conditions, even though these are considerably below those of modern fossil-fuel plants.

Reheating

Another method of improvement is the use of *reheating*, i.e., expanding the steam in a number of turbine stages

to some convenient pressure and reheating to the original temperature or thereabouts, before further work is done in the low-pressure stages of the turbine. Fig. 5 shows the temperature-entropy diagram of such a system; the cycle efficiency is approximately the same as Fig. 4, but the initial temperature is considerably



Temperature-entropy diagram for reheat cycle.
Fig. 5.—615 p.s.i., 725°F, basic cycle efficiency 43.36%.

lower (125°F) than that of Fig. 4. The reheat cycle was first used in 1917; it fell out of use when boilers and turbines could no longer be matched in capacity, since the complication of arranging reheat when boilers were being steamed in banks can better be imagined than described. In the past few years, however, with the return of unit steaming, reheat has triumphantly returned, since it permits high operating pressures while superheat temperatures are kept within the limits imposed by metallurgical considerations.

In the nuclear field, reheating has been proposed without initial superheat[3], as a means of improving cycle efficiency without the technical problems that superheating undoubtedly raises.

Oil-fired Superheaters

Superheating can be incorporated in nuclear plants either by the addition of a separately fired superheater, or by nuclear methods. A nuclear engineer—as opposed to a steam engineer—might be forgiven for being biased against fossil superheat. It is difficult not to think of it as something vestigial—like the pedals of an early motorcycle. Nevertheless, those same pedals could be a very present help in times of trouble. The outlook on fossil superheat depends entirely on one's standpoint; whether one wants to encourage advanced design, or wants minimum operating costs *now*. The designers of Shippingport turned down oil-fired superheat on the grounds that it did not contribute to nuclear technology; the designers of Indian Point include it; both are points of view.

Apart from the fact that it contributes nothing to nuclear technology, and the possible difficulties of fuel supply, there is much to be said for the oil-fired superheater as an interim measure. While it cannot exactly be regarded as an off-the-shelf item, it can be designed with confidence based on many years of experience, and built, comparatively cheaply, from what one might term "ordinary" materials, and neither operation nor maintenance should present any problems worthy of the name.

TABLE 1.
Comparison of Saturated and Superheated Cycles at Indian Point

	Saturated	Superheated
Steam pressure (turbine inlet)	390 p.s.i.	355 p.s.i.
Steam temperature	446°F	1,000°F
Turbine heat rate (B.t.u./kWh)	12,900	10,700
Gross electrical output	163 MW	275 MW
Plant cost ($M)	77	90
Cost per kW	$472	$327
Annual costs (mills/kWh)		
Fixed charges	9.5	6.5
Fuel (nuclear)	6.9 (6.9)	5.8 (4.1)
(oil)	—	
Operation and maintenance	1.1	0.9
TOTAL	17.5	13.2

Some idea of the comparative costs for the Indian Point plant with and without the separate superheating, are given in Table 1.

Nuclear Superheat

Despite the present attractions of fossil superheat, it is firmly believed that it must be considered an interim measure. If we do not believe in the future of nuclear superheat, we are in the wrong business. There are, however, many problems to be solved, in addition to the actual mechanical design of the core; even though this itself will be difficult enough. There will be, in addition, the questions of load-matching of the steam generator and superheater sections, start-up and control problems, possible increase of radioactivity in the steam due to increased corrosion and erosion, and many others.

Not the least of the design problems will be that of thermal insulation between the steam and the moderated water. Whether one visualizes the superheater as a separate reactor (which will probably be the case above a certain size) or as a central section of the core, water will be necessary for moderation purposes, and it will be necessary to keep this down to saturation temperature, without cooling the steam, with a minimum of neutron-absorbing material as a barrier. The differential expansion in the core will also require more than a little thought.

Nevertheless, no problems are insuperable, although the economic production of superheated steam from water reactors of simple construction is by no means round the corner. Considerable effort will be required—and is being applied. Some of the lines of attack being followed at the present moment are listed below.

BORAX-V

The fifth in a celebrated series of boiling water experimental reactors at N.R.T.S., Idaho, is being designed as an exceedingly flexible boiling-plus-superheating facility. Very little information has been released on this unit, but it is believed that the superheater elements (which are water-moderated) will be arranged in individual pipes or shrouds, through which saturated steam will be taken from the top of the vessel, in a downwards direction, the fuel zone consisting of a 1 in.-1½ in. square section, containing several fuel plates of a matrix of uranium oxide-stainless steel, clad in stainless steel. Design is such that the superheater zone can be located first at the perimeter of the core and, later, at the centre. Steam conditions will be in the region of 600 p.s.i., 850°F, and peak power between 20 and 40 MWt.

BONUS

A boiling nuclear superheat reactor plant with an electrical output of 16 MW, which is being built by Combustion Engineering Inc., for the AEC. The plant will be operated by the Puerto Rico Water Resources Authority and is scheduled for criticality in 1963.

PATHFINDER

This plant, with a net output of 62 MW, is being built by Allis-Chalmers, at Sioux Falls, South Dakota, and is described elsewhere in this issue. It is scheduled for criticality in 1962.

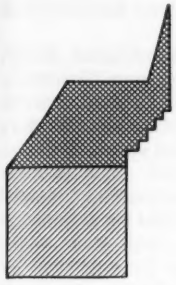
In addition to the foregoing projects, actually under way, there is a considerable amount of work proceeding[4, 5] in the form of design studies and detail development which has not yet been associated with any specific plant.

A Russian project, described in a Geneva paper[6], is under construction in the Ural Mountains. No definite date has been given, but it is estimated that criticality will be achieved in 1961. The reactor, with an electrical output

of 100 MW is to be the first unit of a station having an output of 400 MW. It is a pressure-tube type, graphite moderated, with steam conditions comparable with modern fossil-fuel plants (1,320 p.s.i., and 930°F). It is stated that prototype fuel elements have been tested under boiling and superheating conditions on the Russian APS-1 power plant. The AEA is studying a D_2O-moderated reactor with boiling and superheating light water zones.

REFERENCES

1. Wood, B. "Wetness in Steam Cycles." I.Mech.E. paper, March, 1960.
2. Pearce, Sir Leonard. "Forty Years Development in Power Station Plant" (1940 Thomas Hawkesley Lecture) *Proc. Inst. Mech. Eng.* Feb., 1940.
3. Stone and Webster—Combustion Engineering. "Advanced Pressurized Water Reactor Study." AEC TID–8502.
4. "Nuclear Superheaters for Boiling Water Reactors." Zebroski, E. L., Horst, K. M., and Aline, P. G. (General Electric). Paper No. 46, Nuclear Congress, New York, 1960.
5. "Advanced Water Reactor Systems." Shoupp, W. E., and Wright, J. H. (Westinghouse). Paper No. 43, Nuclear Congress, New York, 1960.
6. "Uranium-Graphite Reactor with Superheated High-Pressure Steam." Dolezhal, N. A., *et al* (U.S.S.R.). Paper P2139, Geneva, 1958.



SUPERHEAT AND THE BWR

2—Nuclear Superheat—Today and Tomorrow

By C. R. BRAUN

(*Manager, Nuclear Power Department (Greendale), Allis-Chalmers Manufacturing Co.*)

SINCE the introduction of nuclear superheat to the American Power Conference[1] in 1958, interest in the concept of nuclear superheat in direct cycle boiling water reactors with modern turbine units has increased considerably.

Evaluation studies made by both industry and the U.S. Atomic Energy Commission indicate that the cost of power from a large nuclear plant using internal nuclear superheat will be less than the equivalent saturated steam plant.

One of the major factors in these projections of nuclear superheat plants is the potential of higher plant efficiencies. If nuclear superheated steam at 1,000°F is supplied to modern design turbine generator units, heat rate reductions of from 10% to 25% can be attained. Design studies indicate that the lower capital costs in the conventional part of the higher-efficiency plant are expected to more than compensate for the cost of the nuclear superheater.

As can be seen from the calculations in Table 1, the capital evaluation of 1 B.t.u./kWh reduction in the heat rate is accepted to reflect a saving $3,000 to $6,000, so that a saving of 1,000 B.t.u./kWh has a capital evaluation of 3 to 6 million dollars, thus providing a strong incentive for developing nuclear superheat.

The high thermal efficiency which results from nuclear superheat is not a panacea. Low capital and operating costs must accompany this improvement.

Superheater Design Considerations

Reactor vessels are costly, and we must learn to get more capacity for a given size, and to design and build them for less. In other words, high power density must be obtained in the superheating region of the core as well as in the boiling region.

The importance of high power density increases with plant capacity. At some point, higher capacity can be obtained only by field fabrication of the vessel or by providing a second reactor. Either approach implies an increase in unit cost. The point where this occurs is not known at this time but is believed to be near 500 MWe.

The superheater must be relatively easy to fabricate and to refuel. It should be free from difficulties which might result from overpressure or thermal expansion, and yet it must conserve neutrons and confine high temperature steam.

Using today's technology, superheater fuel costs are expected to be somewhat higher than boiler fuel costs. Low enrichment fuel, contained safely in thin or low neutron cross-section jackets that are resistant to steam erosion and corrosion, must be developed to reduce these costs. Higher surface temperatures imply better heat transfer and, therefore, higher power density.

Using Nuclear Superheat

Construction of three major facilities to demonstrate the feasibility and economy of nuclear superheat has been authorized: Borax-V, BONUS (Boiling Nuclear Superheat) and Pathfinder refererd to elsewhere in this issue. Of these, the Pathfinder project, with a designed net output of 62 MW (66 MW gross), is by far the largest.

Target (330 MW) Plant

Based on the Pathfinder design data, considerable effort has been expended on the design of a target plant, the schematic diagram of which is shown in Fig. 1. It is recognized that the conceptual designs for this plant probably will change considerably before it is actually built, and we believe that several smaller plants should be built first to develop these improvements. It is interesting to note, however, that extrapolation from the 66 MW Pathfinder plant to 330 MW appears reasonable.

Vessel inside diameter, power density, boiler heat flux and superheater hot-spot temperature are approximately the same in both plants. The development of a moderately high-strength steel was assumed, resulting in a vessel wall thickness of 8 in. Both superheaters use low enrichment uranium dioxide fuel in stainless steel jackets. The 330 MW plant uses the fuel more efficiently, however, due to the

TABLE 1.

Capital Evaluation of reduction in heat rate of 1 B.t.u./kWh

Turbine rating	300 MWe
Heat rating	8,340 B.t.u./kWh
Steam conditions	1,450 p.s.i., 1,000°F
Plant load factor	75%
Annual fixed charge	15%
Fuel-cycle cost	2.7 mills/kWh
Operating hours/year	$8,760 \times 0.75 = 6,570$
Annual fuel cost	$300,000 \times 0.0027 \times 6,570 = \$5,320,000$
Annual value of 1 B.t.u./kWh	$\frac{5,320,000}{8,340} = \$630$
Capital value	$\frac{630}{0.15} = \$4,200$

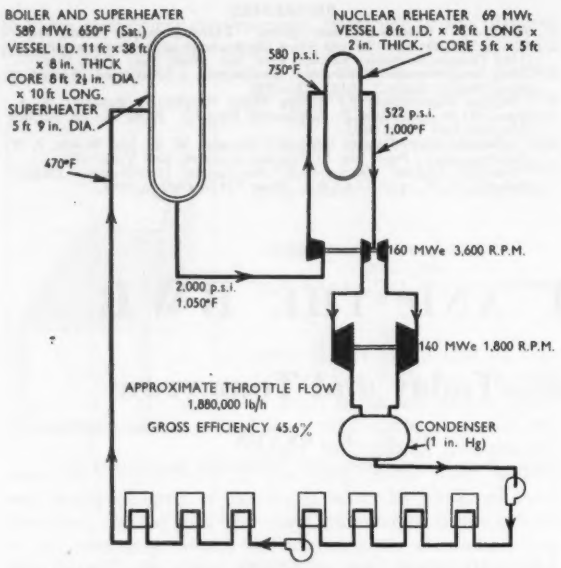


Fig. 1.—Simplified flow diagram for 330 MW project, with nuclear superheater and reheater.

low cross-section of the zirconium alloy superheater support structure.

Natural circulation of the coolant through the boiler region is adequate for this large plant, because the low specific volume of the steam results in low steam void/water fraction. Large volume recirculation pumps are necessary in higher capacity reactors, or in reactors operating at lower pressures.

The separate nuclear reheater is a new development. Obviously, superheater technology will be very useful in its design—particularly since steam conditions approximate those in Pathfinder. A separate reactor is used because reheat is performed at a pressure which is much lower than main reactor pressure. Furthermore, a third nuclear region in the main reactor is believed to be too complex and difficult to control. Nuclear reheaters could not be justified for plants much smaller than 330 MW because of their relatively high capital cost.

Although the reheater vessel is small and inexpensive, control rod drives, radiation shield and other equipment are needed. Also, the core does not conserve neutrons as well as the main reactor.

In this concept, both reactors are in a conventional building which also houses the turbo-generator. They are located in a position which is most favourable for piping, shielding, refuelling, and repairs. Both reactors are provided with reliable systems which prevent gross melting of the fuel jackets under all abnormal conditions.

Thus, the reactor, turbine, condenser, and piping system provide adequate second-line protection against release of fission products. Large exclusion areas are no longer required regardless of population or wind direction. Line losses are minimized by locating the plant close to the centre of power demand.

Small and Medium-sized Plants

Small and medium-sized nuclear plants utilizing modern steam conditions starting at 850 p.s.i./900°F, and ranging on up to about 1,800 p.s.i./1,050°F, will eventually become competitive in their own size range.

Considerable standardization of components such as control drives and fuel elements is needed to make these and large plants competitive. Before these designs can be standardized, the best designs have to be proved through operating experience. Therefore, a number of plants in the 20 to 150-MW range should be operated to develop the best ideas and to evaluate new developments.

Long-range Outlook

It is too early to predict with any certainty the plant designs that are more than 10 years in the future. However, for the purpose of indicating areas where development is needed, several concepts have been explored with the following results.

Integral superheating reactors with recirculation pumps and with a separate reheating reactor appear to be suitable for outputs of approximately 500 MW. Capacities in the order of 1,000 MW probably will require multiple reactors because of vessel fabrication and shipping costs.

Two or more duplicate boiling water reactors with integral superheaters in parallel or a boiling water reactor and a separate superheater in series might be used. A separate nuclear reheater would be used with either arrangement. Operating continuity may be improved by using duplicate or multiple reactors, if reactor shutdown continues to be necessary for refuelling.

Means should be developed for refuelling and fuel shuffling quickly in boiler and superheater regions with the reactor subcritical but at operating pressure. Refuelling while the reactor is operating would be even better. This would not only limit shutdowns to maintenance periods but would improve neutron economy. Frequent additions of fuel would be used to maintain criticality, instead of designing very large amounts of reactivity and poisons into the core.

Superheater fuels that will operate in steam with very high surface temperatures and of low neutron absorption should be developed. Ceramic materials (or cermets) such as silicon carbide should be considered for fuel cladding, at temperatures as high as 2,000°F. If successful, these cladding materials will probably be used to obtain more compact designs rather than to increase average steam temperatures above 1,050°F.

A reactor that supplies steam at supercritical pressures is of interest and appears feasible for very long-range applications. Present concepts use a "once through" type design. Considerably more experience is needed in turbines as well as reactors before any large effort should be expended in designing a plant applying these features.

Conclusion

Electrical power will be produced with fissionable fuels cheaper than it is being produced from coal. How soon this will happen depends largely on how actively the required research and development are pursued. We neither expect nor do we need any "breakthroughs." What is needed is a sufficient number of reactors in operation to evaluate the various design features, to demonstrate the operating and maintenance costs, to prove out the higher power densities, and to demonstrate improved fuels as they are developed. Competitive nuclear power cannot be achieved by a few prototype plants; and we should not adopt a "wait and see" attitude. We should be designing, building, and operating power plants continuously. Only after we have done this will we be able to make realistic design improvements and a realistic determination of the cost of nuclear energy.

REFERENCES

1. Pathfinder Project. Hoffman, J. W. (Northern States Power Co.). Proceedings of the American Power Conference, 1958.
2. Civilian Power Programme (Part IV) U.S. Atomic Energy Commission, February, 1960.

SUPERHEAT AND THE BWR

3—The "Pathfinder" CRBR Project

THE Allis-Chalmers "Pathfinder" plant has already been briefly mentioned in these pages (*Nuclear Engineering*, March, 1960, p. 132) in the form of a brief abstract of an A.S.M.E. paper,[1] and further details[2, 3] received now enable a rather more detailed treatment of this interesting project.

The Pathfinder, or, as it is also termed, the CRBR (Controlled Recirculation Boiling Reactor) is an experimental unit on a commercial scale. With a net output of 62 MW, it is by far the largest nuclear-superheat unit of the BWR type under construction. Scheduled for criticality in 1962, it is located at Sioux Falls, South Dakota, and will be owned and operated by the Northern States Power Co. of Minneapolis (Minn.). Financial assistance for the research and development programme is being provided by the U.S. AEC and the Central Utilities Atomic Power Associates (CUAPA), a group of 10 utilities (Table 1).

As its name of CRBR implies, the plant is of the boiling light water type, with forced recirculation of the coolant, which not only enables a considerably greater output to be obtained from a given core size, but enables accurate control to be obtained, by coolant volume variation, independently of the control rods, and increases the overall efficiency of the plant by eliminating the need for continuous by-passing of steam to the condenser for control purposes. Recirculation of coolant takes place at up to 60,000 gal/min, and the steaming rate is 618,500 lb/h at 600 p.s.i., and 489°F, superheated to 825°F, with a pressure drop in the superheater of 60 p.s.i. The main design parameters are given in Table 2.

Core

Core design, as might be expected with an integral superheater, is comparatively complex, and consists, in effect, of two concentrically located separate cores. The overall core size is 6 ft diameter by 6 ft long; the inner, or superheater, core has a diameter of 2 ft 6 in. The arrangement of the core can be seen from the section of the reactor (Fig. 1), and the core cross-section (Fig. 2) shows the pattern of fuel elements and control rods.

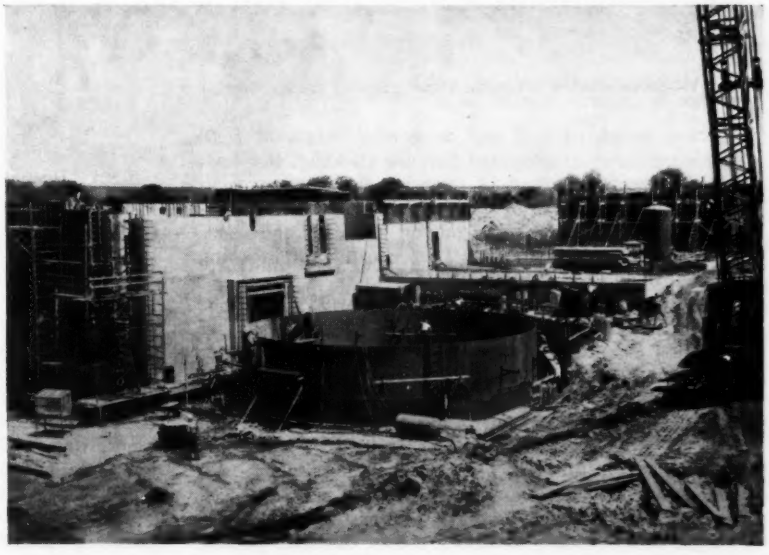
It should be borne in mind that the description "separate," as applied to the boiler and superheater cores, only indicates that the two are mechanically separated. They do, in fact, operate as one reactor from the nuclear point of view, and the improvement in flux distribution,

TABLE 2.—General Design Parameters

Gross thermal power	203 MW
Thermal power boiler region	164 MW
Thermal power superheater	39 MW
Gross electrical power	66 MW
Net electrical power	62 MW
Thermal efficiency	30.5%
Gross heat rate	10,370 B.t.u./kWh
Reactor	
Core height	6 ft
Core Diameter (superheater)	2 ft 6 in.
Core Diameter (boiler)	6 ft
Fuel (boiler) 1.8% enriched UO_2	117 kg
Fuel (superheater) 93% enriched UO_2-S.S. cermet	42 kg
Power density (boiler coolant)	87 kW/litre
Average heat flux (boiler)	130,000 B.t.u./ft²,h
Average heat flux (superheater)	80,000 B.t.u./ft²,h
Maximum heat flux (boiler)	462,000 B.t.u./ft²,h
Maximum heat flux (superheater)	250,000 B.t.u./ft²,h
Reactor operating pressure	600 p.s.i.
Temperature (boiler)	489°F
Temperature (superheater)	825°F
Steam outlet pressure	540 p.s.i.
Recirculation rate	60,000 gal/min
Pumping power	794 kW
Vessel height	31 ft 6 in.
Vessel diameter	11 ft 6 in.
Vessel thickness	3 in.
Containment height	120 ft
Containment diameter	50 ft

TABLE 1.—Members of CUAPA
(Central Utilities Atomic Power Associates)

Central Electric and Gas Company
Interstate Power Company
Iowa Power and Light Company
Iowa Southern Utilities Company
Madison Gas and Electric Company
Mississippi Valley Public Service Company
North-Western Public Service Company
Otter-Tail Power Company
St. Joseph Light and Power Company
Wisconsin Public Service Corporation



Work in progress on the Sioux Falls site; the four courses of the containment shell have been welded and X-rayed. The turbine building (left) and the water treatment building (right) are also progressing.

due to the superheater location in the centre of the core, is shown in Fig. 3.

Fuel Elements

Fuel for the boiler region is in the form of uranium dioxide pellets, assembled within a tube to form rods, these being arranged in bundles, in box form 5 in. square, with

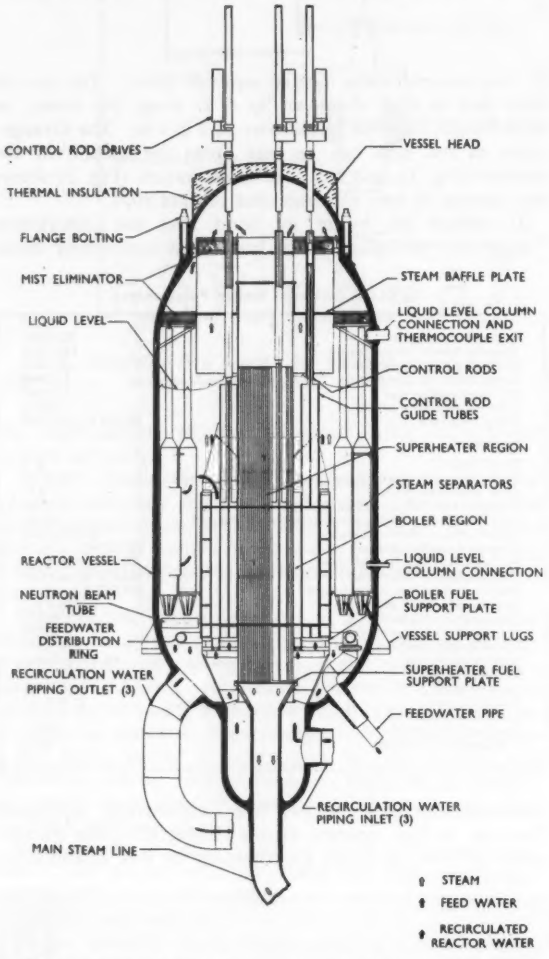


Fig. 1.—Sectional view of reactor vessel, showing coolant flow.

an active length of 6 ft and an overall length of 8 ft. Aluminium alloy is proposed for the cladding, but final decisions await the results of intensive dynamic corrosion studies which have been under way for some time. Alternative studies are being carried out on Zircaloy.

The boiler fuel enrichment is 1.8%, and the total loading (U^{235} equivalent) is 117 kg.

Initially, fuel of very high enrichment (93%) will be used for the superheater, since more high-temperature irradiation experience is available. Later, a much lower enrichment (2%) is proposed, and the reactor design is such that the low-enrichment element can be substituted.

The general arrangement of the first type is shown in Fig. 4. The fuel is in the form of " sandwich " tubes each consisting of a tube of uranium dioxide-stainless steel cermet, clad with inner and outer tubes of stainless steel. Two of these sandwich tubes, of different diameters, are arranged concentrically around a rod of burnable poison,

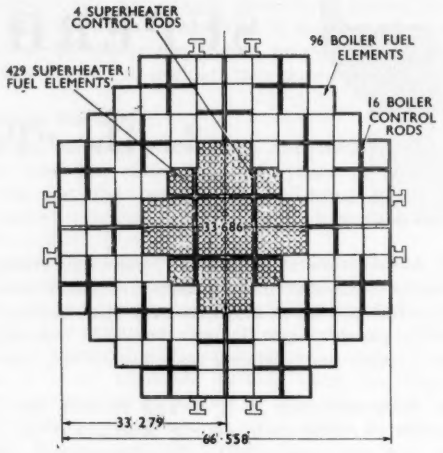


Fig. 2.—Cross-section of core.

the whole being surrounded by two stainless steel containment tubes, which provide a double wall around the element, for heat insulation by means of stagnant steam.

The second design of element is a 7-pin type (Fig. 5) of uranium dioxide clad in stainless steel. As before, the element is surrounded by concentric stainless steel tubes, to give heat insulation by a wall of stagnant steam.

Control

As previously indicated, both control rods and coolant flow are used to achieve overall control. The rods are used to adjust the reactor power level to the system demand; to compensate for burn-up; to adjust the flux distribution within the core, and optimize the burn-up

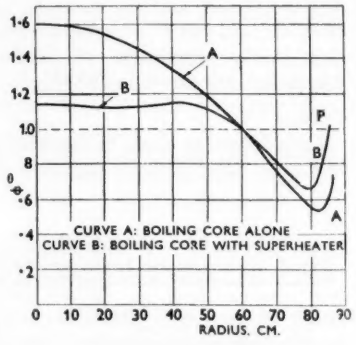


Fig. 3.—Flux distribution in reactor, with and without the superheater core.

pattern. Boron stainless steel is used for the control rods. Coolant control permits gradual automatic control of power, allowing steam pressure to be maintained without the necessity of by-passing steam to the condenser.

Coolant

Light water is used for moderation throughout, and for cooling the boiler portion of the core, and some idea of the flow pattern may be obtained from Fig. 1. Feedwater enters at a distribution ring around the core near the bottom of the vessel. Recirculation takes place in three loops, water being withdrawn from outside the core at the bottom, and returned upwards through the fuel elements in the annular boiler core.

Steam generated leaves the water at the top surface and passes upwards through moisture separators into the central

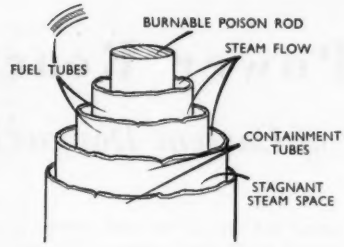


Fig. 4.—Diagram of high-enrichment superheater element showing arrangement of "sandwich" fuel tubes.

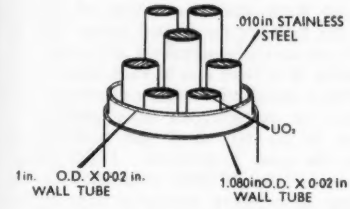
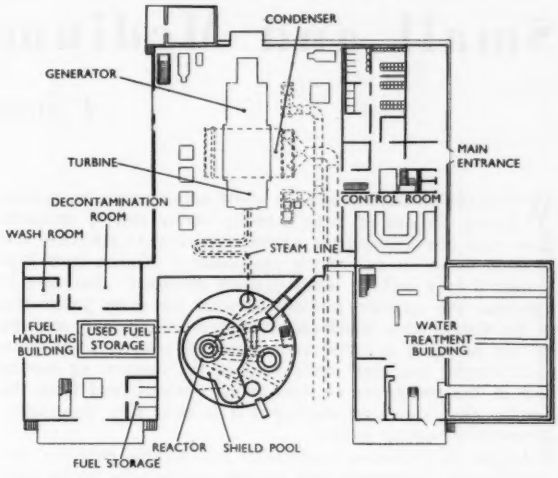


Fig. 5.—Diagram of low-enrichment superheater element.

Fig. 6.—Plan view of Pathfinder station.



superheater zone. In addition, moisture separators of the cyclone pattern are arranged in the annular space between the outside of the core and the pressure vessel; the centrifugal action allows the release of entrained bubbles in the coolant, which might otherwise give rise to cavitation problems in the pumps.

The pumps themselves are of the vertical-shaft centrifugal pattern, with overhung impellers, positioned by fluid-piston type hydraulic bearings. Mechanical seals are used, and the motors are of conventional design. The total pumping power is 794 kW.

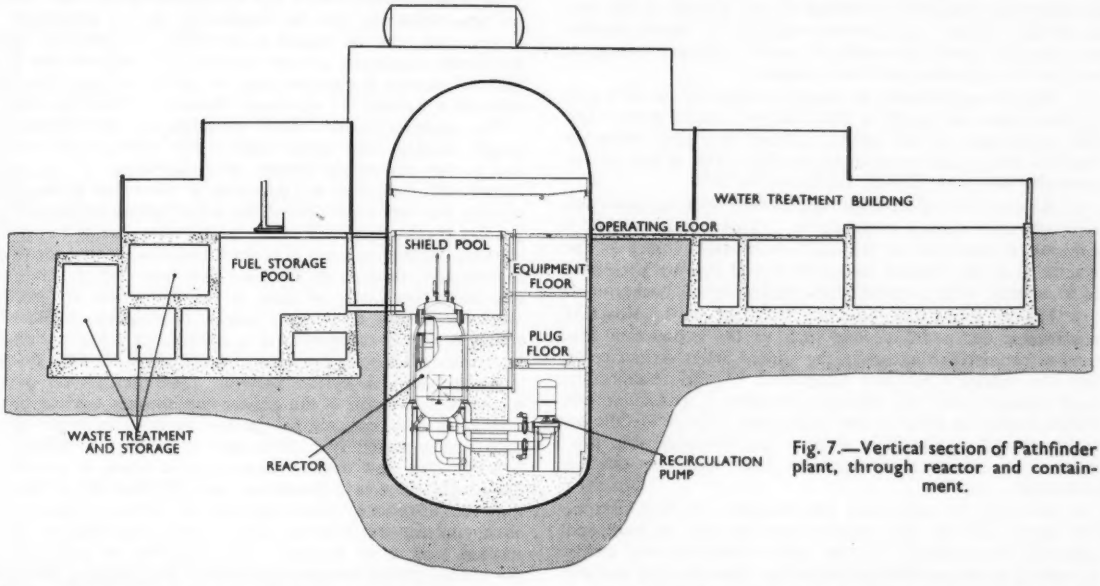


Fig. 7.—Vertical section of Pathfinder plant, through reactor and containment.

Plant Arrangement

The reactor coolant loops, shutdown coolers, etc., are located within a containment shell, 50 ft diameter by 120 ft high, a large portion being below ground level. The general arrangement of the plant can be seen from Figs. 6 and 7.

Shielding of the reactor at the sides is by means of mass concrete; a water tank or pool is used for top shielding, and irradiated fuel elements, removed from the reactor by long-handled grappling tools, are transferred to the storage pool in the adjacent building through a chute. Throughout, an effort has been made to correlate the type of shielding with the necessity for access; i.e., account has been taken of radiation levels and integrated time which operators must spend in the vicinity. In the turbine house, most of the activity is from gamma radiation due to short-lived N^{16}; and equipment is either made inaccessible during running, or limited access is permitted for limited times. Equipment emitting appreciable amounts of activity, but requiring little attention, is grouped together, where possible, behind light shielding, and semi-remote servicing is carried out.

REFERENCES

1. A.S.M.E. Paper 59-A-179. "The Pathfinder Nuclear Plant" by Clifton B. Graham (Chief Engineer, Nuclear Power Department, Allis-Chalmers Manufacturing Company).
2. American Power Conference Paper 43R 9580 "Superheated Steam from Nuclear Energy" by C. R. Braun (Manager) and C. B. Graham (Chief Engineer, Nuclear Power Department, Allis-Chalmers Manufacturing Company).
3. ACNP-5924 Pathfinder Atomic Power Plant Technical Progress Report. U.S. AEC Feb. 1960.

Small and Medium Power Reactors

A Survey of Current Designs and Markets

WITH the general recession in world requirements for nuclear power stations of large capacity, many reactor designers have been re-examining the potential markets in the small and medium power range and the conference in Vienna from September 5 to 9 will see many systems discussed. For ease of reference the attached pull-out itemizes the main parameters of the designs upon which manufacturers are currently working or are prepared to offer as commercial plant. Continuous improvement has been made both in the engineering aspects and in the economics of these small systems, and from the number that are being developed it is clear that commercial competition will be intense.

At the 1955 Geneva conference considerable publicity was given to the opportunity that nuclear energy afforded for providing unlimited, relatively cheap power in remote and undeveloped areas. A more realistic assessment, however, of the problems has shown that not only are the economics in the main unfavourable but that demands for skilled personnel continually in attendance, and the background of expertize necessary to maintain the associated services, put the small reactor out of reach of under-industrialized areas.

These points have been generally recognized and there are no reasons for supposing that the grounds upon which the arguments were based have undergone any change in the past few months. There are, however, markets for small reactors other than for power generation in under-developed countries. These can be classified into four categories:—

1. Reactor experiments in which a new technique or a new variant of an old system is tried out on a small scale. The first experiments on all reactor systems have been made on reactors with a generating capacity of 50 MW or less as, for example, SRE, G1, EBWR, DFR and the S1W.

2. Reactors for specialized applications such as powering remotely sited military installations. This is quite a distinct application from that of the under-developed country as the reactor is to be located on territory and run by personnel of a country with a considerable technological background.

3. Marine propulsion units for merchant ships. Reactors constructed for naval vessels such as the production line runs of submarine reactors in the United States do not come into this category but into category 2. Naval reactors are built because they are capable of doing a particular job which cannot be done in any other way. There is thus no real economic competition whereas for merchant ship propulsion the ultimate incentive at least must be one of economics.

4. Reactors for experience and training. In this instance the reactor will be of a proven type but will be built and operated by newcomers to the nuclear field (be they utility organizations or nationalized electricity undertakings) and the prime interest is in building up experience of the techniques involved in the operation of a nuclear power station. The first reactor in this capacity can be said to be BR-3 due to go critical at the end of this year in Belgium (*Nuclear Engineering*, August, 1960, p. 337).

Taking these categories in order, it is perhaps improper to speak of markets for prototypes. Nevertheless, the contract for the construction of one may be a profitable undertaking for an industrial concern and indeed more profitable than introducing a line of production models (if such a term can be used). The prototype is incidental to the main development theme of the reactor in question and only a limited continuation of this line of business can be expected. In the United States there are plans to develop the boiling water reactor through the medium of a number of advancing prototypes of medium power output but even so the total number is small and the real aim at present is the development of the unit of say, 300 MW size.

Not so the specialist and military reactors and it is this class that sees least competition from alternative forms of energy production. Dominating this field are the United States who, in addition to their massive submarine programme, are proposing to install nuclear propulsion in at least one of each major class of service ship. Competitive designs have been developed for remote site operation as, for example, an army outpost or almost inaccessible areas in the far north and a mounting impetus is being given to the space programme. The U.S.S.R. has put to sea *Lenin* powered by its three pressurized water reactors which, by opening the northern seaway 25 days earlier than usual, has already proved its specialist value, almost irrespective of the economics of the ship concerned. We presume also that the U.S.S.R. has a nuclear submarine programme but the extent of this is not fully known. France and the United Kingdom have also nuclear submarine programmes of modest dimensions; to date they have shown no interest in the remote site aspects. The main market therefore, at present in the Western world, is with the United States Government and this will be restricted to U.S. companies.

The marine reactor is a highly specialized unit and although many organizations would like to develop small power reactors on land which can then be adapted for marine propulsion, the marine unit must be treated as an entity. Innumerable studies have been conducted all over the world to evaluate the potentials of nuclear propulsion and no doubt the next few years will see a number of the paper studies become real projects.

The opportunity for reactor designers and manufacturers to supply utilities with small reactors for training and teaching and gaining experience appears most promising. It has become increasingly clear over the past year or more that utility organizations are very conscious of the novel nature of many of the problems that they will meet in installing their first nuclear stations. Many are loath to embark upon full-scale construction immediately, because of the risks that they run of obtaining a low utilization factor at least in the first years of operation. We have already quoted the reactor in Belgium, BR-3, which comes into this category, but a number of other nations are interested in adopting the same technique, for example, Portugal and the South American nations. The market has perhaps increased as a result of the greater gap between nuclear generation costs and conventional generation costs in large stations than was expected two years ago—especially as utilities will feel that they now have a longer time in which to prepare for the advent of nuclear generation on a big scale but at the same time feel anxious to gain experience in the near future so that advantage can be taken as soon as the economics of the big stations look more hopeful. It is possible, for example, that the United States independent utilities may prepare themselves by installing small reactors but the response to G.E.'s "Operation Know-how" which proposed the mass production of 5 MW BWRs essentially for training purposes, was disappointing.

There are few industrialized nations who have a continuing requirement for electricity generating units of small size in the near future. The back pressure turbine, process steam reactor may become an attractive proposition to chemical engineering organizations, paper mills and the like where the load factor can be guaranteed but in the main companies are still reluctant to be dependent upon a single reactor unit for their power and steam. In any case the cost of producing energy by other means is certainly less today and it appears highly improbable that until generation costs of large base load nuclear stations are less than those of conventional stations the same will not be true for the small and medium power units.

Nuclear Engineering

REF. SHEET No. 2 SMALL POWER REACTORS

	GENERAL						FUEL ELEMENT					REACTOR PHYSICS							
	Designer/Contractor	Reactor designation	Type	Output Th (MW)	Output E (MW)	Efficiency %	Type	Dimensions length (in.)	Dimensions dia. (in.)	Cladding Material	Cladding Wall (in.)	Neutron energy e V	Conversion ratio	$k\infty$ (hot)	$k\infty$ (cold)	k eff (hot)	k eff (cold)	Neutron flux Thermal (av)	Neutron flux Thermal (max)	Excess temp $\Delta k/k$
1	Allis-Chalmers	Elk River	BWR	51.1	20.46	31.9	Th O_2–UO_2 pellets in S.S. tubes. 25 tubes/element	60 O.D.	0.452 O.D.	Boron S.S.	0.02	0.062	0.396	1.1849	1.1825	1.0831	1.1265	1.15×10^{13}	—	0.0428
2	Allis-Chalmers	A-C–NCBWR	BWR	163	51.3	31.5	Solid cylindrical UO_2 pellets, 2.8% enriched	78 active	0.36 O.D.	304 S.S.	0.02	0.065	0.48	1.1922	1.2349	1.1235	1.1955	2.6×10^{13}	—	0.072
3	Allis-Chalmers	A-C–FCBWR	BWR	163	51.3	31.5	Solid cylindrical UO_2 pellets, 3.2% enriched	78 active	0.36 O.D.	304 S.S.	0.02	.056	0.48	—	—	1.18	1.26	1.8×10^{13}	7.2×10^{13}	0.08
4	Belgonucleare and Indatom	—	BWR	122.4	34	27.8	Sintered UO_2 pellets	—	9.75 mm	S.S.	0.38	—	0.44	—	—	1.19	1.22	2.4×10^{13}	—	—
5	Combustion Engineering	ICB–SI	BWR	61	16.5	27.3	Cylindrical UO_2 rods consisting of sintered pellets 0.39 in. dia.	54	—	AISI 347 S.S.	0.018	0.047	0.4	1.227	1.260	1.136	1.198	1.4×10^{13}	5.9×10^{13}	4.3%
6	Combustion Engineering	DCB–M2	BWR	165	53	30.4	As above but with pellets of 0.434 in. dia. (upper region) and 0.390 in. dia. (lower region)	72	—	AISI 347 S.S.	0.020 large 0.018 small	0.049	0.6	1.15	1.19	1.10	1.13	2×10^{13}	7×10^{13}	4.8%
7	General Electric	—	BWR	45	12.5	—	36 rods per assembly	54	0.563	Zircaloy	0.033	—	0.53	—	1.22	—	1.13	2×10^{13}	—	—
8	General Electric	—	BWR	166	50	—	49 rods per assembly	82	0.43 O.D.	S.S.	0.018	—	0.41	—	1.30	—	1.25	1.8×10^{13}	—	—
9	General Nuclear Engineering Corporation	DCB–M1	BWR	102	32	30.1	Cylindrical UO_2 rods consisting of sintered pellets 0.454 in. dia.	64	—	Zircaloy 2	0.020	0.049	0.6	1.16	1.195	1.095	1.149	2.3×10^{13}	8×10^{13}	4.3%
10	Mitchell Engineering–AMF	—	BWR	110	30	27.3	Sintered UO_2 pellets .41 in. dia.	—	—	S.S. 304 L	.015	—	—	—	—	—	—	—	—	—
11	Aerojet General	ML–1	GC	3.3	.33	10	Sealed tubes containing UO_2–BeO pellets	32	1.72 O.D.	Hastelloy-X	0.03	—	~0	1.693	1.70	1.017	1.021	1.9×10^{13}	7.4×10^{13}	0.04
12	G.E.C. and Simon-Carves	—	GC	97	30	31	G.E.C. cross flow type (enriched UO_2)	—	—	S.S.	0.01	Th.	0.3	1.295	1.311	1.11	1.16	3.37×10^{13}	8.8×10^{13}	4%
13	Imperial College/Humphreys and Glasgow	LPR	GC	110	24.5	22.3	Nat. U rod	33	1	Magnox	0.035	Th.	—	—	—	—	—	—	—	—
14	General Atomic	—	GC	121	38.6	33	Cluster of 19 rods	6.4 ft	0.375	S.S. 316	0.010	0.10	0.58	1.28	1.43	1.16	1.30	2.4×10^{13}	4.8×10^{13}	10%
15	A. B. Atomenergi ASEA	R3 Adam	D_2O	65	10	—	Sintered UO_2 rods in 19-rod bundles	—	—	Zircaloy 2	0.7 mm	—	—	1.0735	1.146	1	—	1.3×10^{13}	2.8×10^{13}	—
16	Siemens–Schuckertwerke	SNDR 1b	D_2O	200	55	25	Cluster type, 37 rods per cluster	—	1.17cm O.D.	Zircaloy 2	0.6 mm	—	0.793	1.107	1.16	1.017	1.088	6.4×10^{13}	1.6×10^{14}	2.2
17	Atomics International*	Piqua	OM	45.5	11.4	25	Double concentric cylinders. Metal alloy comprising U, Mo, Al, 1.94% enriched, double cyl.	—	5.25 O.D.	Al	0.035	Th.	0.60	1.22	1.23	1.10	1.11	1.3×10^{13}	2.8×10^{13}	1.06%
18	Hawker Siddeley	—	OM	66.2	20	30.2	UO_2 pellets, ¼ in. O.D.	—	—	S.S.	—	—	—	1.222	—	1.106	—	2×10^{13}	—	—
19	ACEC	—	PWR	40.9	10.5	25.7	UO_2 rods	—	8.7 mm	S.S.	0.05 cm	0.025	0.443	—	—	1.097	—	1.83×10^{13}	5.14×10^{13}	9%
20	Alco Products	—	PWR	47.5	11.75	24.7	4% enriched UO_2 in 0.04 in. I.D. pins assembled in tubes	49	—	S.S. 347	0.02	0.046	0.30	1.296	1.325	1.166	1.241	1.2×10^{13}	4.05×10^{13}	0.075
21	Allis-Chalmers	A-C–SPWR	PWR	62	15.8	25.5	Solid cylindrical UO_2 pellets 3.2% enriched	48 active	0.457 O.D.	304 S.S.	0.02	0.053	0.53	—	—	1.09	1.14	2×10^{13}	7.6×10^{13}	0.05
22	Allis-Chalmers	A-C–ELPHR	PWR	40	—	—	Rod-type, UO_2 pellets 3% enriched	45 active	62¾	304 L S.S.	0.02	0.05	0.55	1.25	1.28	1.13	1.17	1.12×10^{13}	5.04×10^{13}	0.043
23	Babcock and Wilcox Ltd.	—	PWR	210	60	28.5	Enriched UO_2 pellets in cylindrical rods	—	0.395 (10 mm)	Zircaloy	—	—	0.48	—	—	—	—	—	—	—
24	Babcock and Wilcox Co.	SPWR	PWR	62.3	16.5	26.5	UO_2 rod	—	0.35	304 S.S.	0.032	—	0.4	1.273	1.241	1.083	1.112	9.7×10^{13}	4.9×10^{13}	0.0295
25	Combustion Engineering	P–S1	PWR	62.4	16.5	25	Cyl. UO_2 rods comprising sintered pellets 0.343 in. dia.	54	—	AISI type 348 S.S.	0.026	0.047	0.4	1.29	1.34	1.12	1.17	1.5×10^{13}	5.7×10^{13}	4.4%
26	Combustion Engineering	P–S2	PWR	80	24	28.1	Cyl. UO_2 rods comprising sintered pellets	52	—	AISI type 347 S.S.	0.023	0.05	0.7	1.23	1.31	1.10	1.22	1.7×10^{13}	5.4×10^{13}	9.8%

21	Allis-Chalmers	A-C–SPWR	PWR	62	15.8	25.5	sembled in tubes Solid cylindrical UO_2 pellets 3.2% enriched	48 active	0.457 O.D.	304 S.S.	0.02	0.053	0.53	—	—	1.09	1.14	2×10^{13}	7.6×10^{13}	0.05
22	Allis-Chalmers	A-C–ELPHR	PWR	40	—	—	Rod-type, UO_2 pellets 3% enriched	45 active	62¼	304 L S.S.	0.02	0.05	0.55	1.25	1.28	1.13	1.17	1.12×10^{13}	5.04×10^{13}	0.043
23	Babcock and Wilcox Ltd. ..	—	PWR	210	60	28.5	Enriched UO_2 pellets in cylindrical rods	—	0.395 (10 mm)	Zircaloy	—	—	0.48	—	—	—	—	—	—	—
24	Babcock and Wilcox Co. ..	SPWR	PWR	62.3	16.5	26.5	UO_2 rod	—	0.35	304 S.S.	0.032	—	0.4	1.273	1.241	1.083	1.112	9.7×10^{12}	4.9×10^{13}	0.0295
25	Combustion Engineering ..	P–S1	PWR	62.4	16.5	25	Cyl. UO_2 rods comprising sintered pellets 0.343 in. dia.	54	—	AISI type 348 S.S.	0.026	0.047	0.4	1.29	1.34	1.12	1.17	1.5×10^{13}	5.7×10^{13}	4.4%
26	Combustion Engineering ..	P–S2	PWR	80	24	28.1	Cyl. UO_2 rods comprising sintered pellets 0.312 in. dia.	52	—	AISI type 347 S.S.	0.023	0.05	0.7	1.23	1.31	1.10	1.22	1.7×10^{13}	5.4×10^{13}	9.8%
27	Humphreys and Glasgow—Babcock and Wilcox	—	PWR	70	20	28.6	Clad rod	78	0.395	Zircaloy	—	—	—	—	—	—	—	—	—	—
28	Lockheed Nuclear Products	—	PWR	42.7	11.5	23.4	Slightly enriched UO_2 tubular element	—	0.4	S.S.	0.022	0.069	0.578	1.398	1.392	1.145	1.181	1.02×10^{13}	2.36×10^{13}	0.0267
29	Westinghouse Electric ..	BR-3	PWR	—	11.4	25.7	Rods assembled in boxes 5.25 in. square	78.75	—	S.S. type 348	0.021	0.025	outer 0.435 inner 0.469	—	—	1.097	—	2.4×10^{13}	9.5×10^{13}	9%

* U.K. licensee : English Electric.

	REACTOR PHYSICS			CORE												COOLANT						
										Fuel Rating		Power densities		Burn-up				Temperature		Flow		
	Reactivity f.p. poisons $\Delta k/k$	Compensation burn-up $\Delta k/k$	Max. excess reactivity $\Delta k/k$	Shape	Size, dia. × height (in.)	No. of fuel assemblies	Lattice (in.)	Critical mass	Core loading kg–U235	(Av) kW/kg	(Max) kW/kg	(Av) kW/l	(Max) kW/l	(Av) MWd/t	(Max) MWd/t	Material	Pressure (p.s.i.)	Inlet °F	Outlet °F	(Through core)	(Through system) lb³/h	Mass in system (gal)
1	0.0271	0.0563	0.1265	Cyl	54.28×60	148	5×5 ¾ pitch	—	—	14.5	—	25.6	88.3	9,500	—	H_2O	950	450	538	35.6 lb/lb steam	258,000	4,800
2	0.0372	0.0863	0.1955	Cyl	66×78	232	6×6 0.611 pitch	—	279	—	—	33.4	133.6	10,000	—	H_2O	1,300	566	577	29,400 g.p.m.	—	—
3	0.04	0.14	0.26	Cyl	66×78	200	6×6 0.611 pitch	—	—	—	—	36.6	146.4	12,000	—	H_2O	1,250	561	574	40,000 g.p.m.	—	—
4	7.5%	—	—	Cyl	1,621 mm × 1,763 mm	128	Square	—	7,260	14.94	—	33.6	—	—	—	H_2O	70.3 kg/cm² abs	261°C	285°C	542.9 kg/s	—	—
5	2.4%	9.5%	16.4%	Cyl	57.5×54	104	0.625 in. square pitch	—	4,840	13.0	55	27.4	116	10 MWd/kg	25 MWd/kg	H_2O	935	505	538	12,000	12,800	20t
6	−2.9%	−3.8%	13%	Cyl	73×72	216	0.625 square pitch	—	10,950	15.3	51.3	33.5	112	19.2 MWd/kg	>40 MWd/kg	H_2O	1,300	564	578	15,000	15,000	40t
7	—	—	—	Cyl	51×54	72	—	—	10,700 lb UO_2	85,000 Btu/h-ft²	—	24 kW/litre	—	8,000 MWd/t	—	H_2O	890	510	530	2.5×10^4 lb/h	2.5×10^4 lb/h	—
8	—	—	—	Cyl	75×82	164	—	—	26,200 lb UO_2 slightly enriched	91,200	—	29	—	12,000	—	H_2O	1,025	536	547	10.4×10^4 lb/h	5.84×10^5 lb/h	—
9	−3.6%	−3.3%	13%	Cyl	64.5 × 66.25	164	0.639 square pitch	—	8,050 kg of U	12.6	44	28.7	100	11 MWd/kg	>30 MWd/kg	H_2O	1,300	563	578	8,750 g.p.m.	8,750 g.p.m.	17t
10	—	—	—	Cyl	70×72	188	—	—	—	—	—	24.5	—	10,000 MWd/t	—	H_2O	1,200	541	567	12.9 ft³	—	—
11	2.6	0.8	2.1	Hex	11.9×22	61	2.37 to 2.86	25	49	69	117	700 kW/ft³	1,200 kW/ft³	4.5%	9.2%	N_2+ 0.5% O_2	315	800	1,200	90,000 lb/h	92,000 lb/h	52 lb
12	3%	7%	14%	Cyl	108×118	87	11.0 triangular	—	3.464 te	28 MW/te	55 MW/te	142 kW/ft³	248 kW/ft³	10,000 MWd/te	15,000 MWd/te	CO_2	600	260°C	538°C	682 lb/sec	682 lb/sec	20,000 lb
13	—	—	—	—	306×276	9,160	Triangular	—	72 te	1.53 MW/t	3.19 MW/t	—	—	2,160 MWd/t	4,500 MWd/t	CO_2	60	200°C	385°C	1,230 lb/sec	—	—
14	4%	16%	30%	—	8 ft×6.4	520	3.8 in. square	175	3,038 total U 338 kg U-235	36.7	87.5	13.2	26.4	57,800	—	Helium	1,100	525	1,000	195 lb/sec	195 lb/sec	1,600 lb

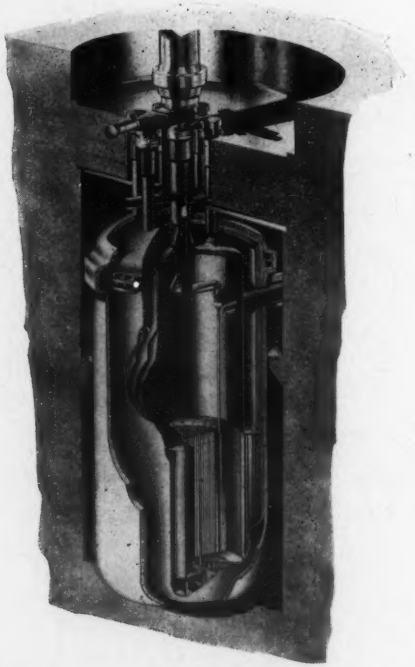
13	—	—	—	—	306×276	9,160	Triangular	—	72 te	1.53 MW/te	3.19 MW/te	—	—	2,160 MWd/te	4,500 MWd/te	CO_2	60	200°C	385°C	1,230 lb/sec	—	—
14	4%	16%	30%	—	8 ft×6.4	520	3.8 in. square	175	3,038 total U 338 kg U-235	36.7 MW/t	87.5 MW/t	13.2	26.4	57,800 MWd/t	—	Helium	1,100	525	1,000	195 lb/sec	195 lb/sec	1,600 lb
15	—	—	—	Cyl	3.62 m×3 m	140	27 cm square	—	20 tons UO_2	3.3 MW/t	9 MW/t	—	—	~6,000	—	D_2O	34 at.	205°C	220°C	1,020 kg/s	—	70t
16	3.6	1.6	8	Cyl	314.2 cm×367.4 cm	242	Hex 272 mm pitch	4t UO_2	13.49 t UO_2	16.8	40.3	121 W/cm rod-length	423 W/cm rod-length	4,000	5,000	D_2O	90 kg/cm²	251.5°C	280°C	4.65×10⁶ kg/h	4.65×10⁶ kg/h	20t
17	1.8%	1.8%	7.86%	Cyl	58×54	85	Triangular 6 in. centre to centre	31.4	6,900 1.94% enrichment	6.6	17.2	19.4	50.5	3,000 te	<5,000 te	Isometric terphenyls	120	518	575	5.5×10⁶ lb/h	5.5×10⁶ lb/h	110,000 lb
18	—	—	1.059	—	60×64.25	29	Triangular	—	8 te U, 1.7% enriched	9 MW/te	—	21 W/cc	—	10,000 MWd/te	—	Terphenyl and associated polymer	74	316°C	341°C	2,250 lb/sec	—	34t approx.
19	5%	5%	19%	Polygonal prism	85.4 cm×142 cm	32	1.22 cm square	—	2,277 kg-UO_2	20.4	95	50.5	236	5,940	—	H_2O	141 kg/cm²	255°C	268°C	—	2,265 t/h	—
20	0.036	0.13	0.241	Cyl	—	61	9×9	17	137	1,250	5,750	33.4	153.6	10,500	40,000	H_2O	2,000	448	528	12,000 g.p.m.	12,000 g.p.m.	14,300 lb
21	.03	.06	0.14	Cyl	—×48	120	6×6 ¾ pitch	—	—	—	—	38.1	148	7,800	—	H_2O	1,600	490	505	30,000 g.p.m.	—	—
22	0.038	0.092	0.17	Cyl	45×45	32	10×10 ¾ pitch	—	103	~11.75	—	33	~150	9,000	—	H_2O	970	~400	~430	~4.277×10⁶ lb/h	~4.277×10⁶ lb/h	—
23	—	—	—	Cyl	74×99	76	7 square	—	15.2 te UO_2	15.7 MW/te	—	29	—	10,000	—	H_2O	1,750	586	561	—	24×10⁶ lb/h	—
24	0.0825	0.0825	0.118	Cyl	—	40	Square	—	174.09 Kg	358 kW/kg	—	32.33	—	17,210	—	H_2O	1,750	489	525	—	5.6×10⁶	—
25	−2.4%	−7.9%	14.7%	Cyl	45×54	91	0.564 in. triangular pitch	—	3,660 kg U	17	59	44	155	12 MWd/kg	30 MWd/kg	H_2O	2,000	502	548	10,000 g.p.m.	10,400 g.p.m.	16t
26	−1.4%	−6.9%	18.1%	Cyl	45×52	91	0.456 triangular pitch	—	4,424 kg U	18.5	51.5	61	170	13 MWd/kg	25 MWd/kg	H_2O	2,000	589	620	16,500 g.p.m.	17,400 g.p.m.	13t
27	—	—	—	—	54×78	40	7 in. square	—	5.1 te UO_2	13.7 MW/te	—	23.8	—	10,000 te	—	H_2O	1,750	536	561	—	8×10⁶ lb/h	—
28	0.0275	0.0991	0.1533	Cyl	—	32	0.463 square	77 kg U-235	2,970.39 kg U	—	—	42.7	76.7	37.6%	51.5%	H_2O	900	430	454.8	4.91×10⁶ lb/h	4.91×10⁶ lb/h	27,300 lb
29	5%	5%	19%	Polygonal prism	33.52×55.91	32	0.48	—	2,300 kg enriched U	18	—	50.5	—	5,940	—	H_2O	503	2,000	491	515	4.5×10⁶ lb/h	5×10⁶ lb/h

	COOLANT			MODERATOR			CONTROL			REACTOR VESSEL		PROTECTION		STEAM CONDITIONS				
						Oprtng. conditions								H.P.		L.P.		Flow H.P., L.P. lb/h
	Pumping power	Heat exchangers, No. and Type	Material	Weight	Temp. °F	Pressure p.s.i.	No. of rods	Worth Δ k/k	Constructional details	Material	Dimensions, dia. × height	Main shield	Containment	Temp.	Press.	Temp.	Press.	
1	Nat. circ.	4 shell and U-tube	H_2O	—	538	950	13	~0.183	Cruciform shape absorber sections boron S.S.	3 in. low alloy steel	7 ft×25 ft	Concrete	Carbon steel des. int. pres. 21 p.s.i.g.	825	600	—	—	225,000
2	None	4 feed heaters, moisture separator and reheater (As above)	H_2O	—	577	1,300	24	~0.234	(As above)	—	11 ft I.D.×32 ft	—	—	569	1,200	—	—	692,100
3	None		H_2O	—	574	1,250	21	~0.29	(As above)	Type A 302 grade B steel lined with 304 S.S. 4 in. thick	8.25 ft I.D. ×32 ft	—	—	569	1,200	—	—	692,100
4	—	2 shell and tube type	H_2O	2,533 kg	285°C	70.3 kg/cm² abs	12	19.5%	Cruciform in boron S.S. width 400 mm ; thickness 6 mm	ASTM A-212 Gr, B or A-302 Gr, B steel	2,472 mm×8,784 mm	Lead and heavy concrete	Steel capsule dia. 23,000 mm height 38,000 mm	246°C	34 kg/cm² abs	—	—	57.85 kg/s
5	.21 MW	2 vertical U-tube steam generators and 2 horizontal straight tube superheaters	H_2O	—	525	935	24	21%	Cruciform absorber blades 0.25 in. thick; 9.3 in. span; boron S.S. with Zircaloy 2 followers	3.375 in. thick SA 212 B steel internally clad with S.S.	7 ft 6 in. I.D.×24½ ft	Concrete	Steel cyl. 32 ft dia. by 46 ft high	520	500	—	—	153,000 lb/h
6	.27 MW	None	H_2O	—	578	1,300	21	16%	As above but 15 in. span	4 in. thick SA 302 B steel clad internally with S.S.	8 ft 4 in. I.D. ×32 ft	Concrete	Steel sphere 120 ft dia.	574	1,250	—	—	668,000
7	—	—	H_2O	—	530	890	21	0.83%	Cruciform 54 in. long; 0.887 in. wide; blade thickness 0.375 in.	Carbon steel clad with S.S.	74 in.×310 in.	Cylindrical biological	Domed cylinder	528	875	—	—	1.5×10⁵ lb/h
8	—	—	H_2O	—	536	547.6	32	0.75%	Cruciform 82 in., width 8.75 in.; blade thickness 0.375 in.	As above	120 in.×486 in.	Cylindrical biological	Sphere	547.6	1,025	—	—	5.84×10⁵
9	.13 MW	—	H_2O	—	578	1,300	13	22%	Cruciform absorber blades 0.25 in. thick ; 15 in. span boron S.S. with Zircaloy 2 followers	5.12 in. thick SA 212 B steel clad with S.S.	7 ft 7 in.×25 ft 5 in.	—	Steel cyl. 65 ft dia.×112 ft high	574	1,250	—	—	401,700 lb/h
10	—	—	H_2O	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
11	.152 MW	One gas to gas recuperator 4-pass	H_2O	190 lb in core	185	25	12	5.5 total	Flat blades as six pairs; one pair entering each	S.S. pressure tubes	—	8-in. lead 30 in.	—	No steam—direct Brayton cycle gas turbine				

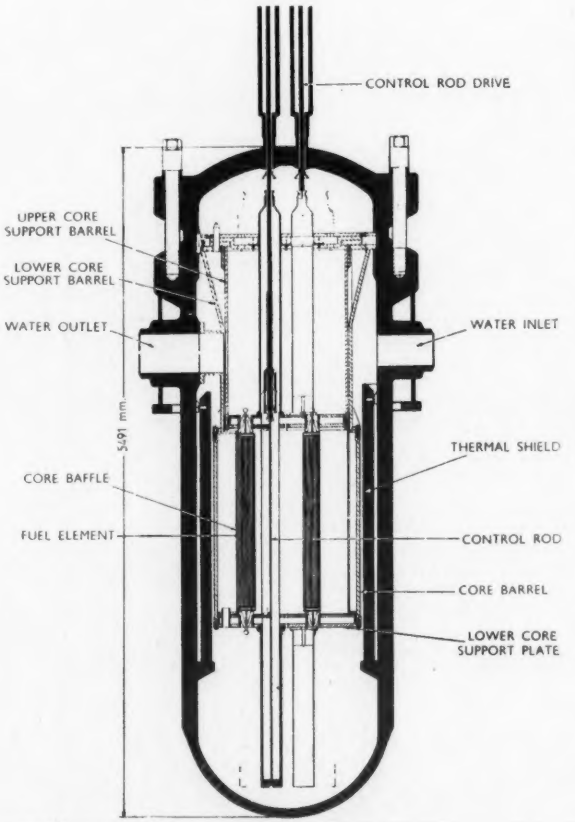
21	.03	.06	0.14	Cyl	—×48	120	6×6 ¾ pitch	—	—	—	—	38.1	148	7,800	—	H_2O	1,600	490	505	12,000 g.p.m. 30,000 g.p.m.	12,000 g.p.m. —	14,300 lb —
22	0.038	0.092	0.17	Cyl	45×45	32	10×10 ¾ pitch	—	103	~ 11.75	—	33	~ 150	9,000	—	H_2O	970	~ 400	~ 430	~ 4.277× 10^6 lb/h	4.277× 10^6 lb/h 24× 10^6 lb/h	—
23	—	—	—	Cyl	74×99	76	7 square	—	15.2 te UO_2	15.7 MW/te 358 kW/kg	—	29	—	10,000	—	H_2O	1,750	586	561	—	—	5.6× 10^6
24	0.0825	0.0825	0.118	Cyl	—	40	Square	—	174.09 Kg	17	59	32.33	—	17,210	—	H_2O	1,750	489	525	—	10,400 g.p.m.	16¢
25	−2.4%	−7.9%	14.7%	Cyl	45×54	91	0.564 in. triangular pitch	—	3,660 kg U	18.5	51.5	44	155	12 MWd/kg	30 MWd/kg	H_2O	2,000	502	548	10,000 g.p.m.	17,400 g.p.m.	13¢
26	−1.4%	−6.9%	18.1%	Cyl	45×52	91	0.456 triangular pitch	—	4,424 kg U	13.7 MW/te	—	23.8	—	10,000 te	—	H_2O	1,750	536	561	16,500 g.p.m.	8× 10^6 lb/h	—
27	—	—	—	—	54×78	40	7 in. square	—	5.1 te UO_2	—	—	42.7	76.7	37.6%	51.5%	H_2O	900	430	454.8	—	4.91× 10^6 lb/h	27,300 lb
28	0.0275	0.0991	0.1533	Cyl	—	32	0.463 square	77 kg U–235	2,970.39 kg U	18	—	50.5	—	5,940	—	H_2O	503	2,000	491	4.91× 10^6 lb/h 515	4.91× 10^6 lb/h 4.5× 10^6 lb/h	5× 10^6 lb/h
29	5%	5%	19%	Polygonal prism	33.52× 55.91	32	0.48	—	2,300 kg enriched U													

	COOLANT			MODERATOR			CONTROL			REACTOR VESSEL		PROTECTION		STEAM CONDITIONS					
					Oprtng. conditions									H.P.		L.P.		Flow H.P., L.P. lb/h
	Pumping power	Heat exchangers, No. and Type	Material	Weight	Temp. °F	Pressure p.s.i.	No. of rods	Worth Δ k/k	Constructional details	Material	Dimensions, dia. × height	Main shield	Containment	Temp.	Press.	Temp.	Press.	
1	Nat. circ.	4 shell and U-tube	H_2O	—	538	950	13	~ 0.183	Cruciform shape absorber sections boron S.S.	3 in. low alloy steel	7 ft×25 ft	Concrete	Carbon steel des. int. pres. 21 p.s.i.g.	825	600	—	—	225,000
2	None	4 feed heaters, moisture separator and reheater (As above)	H_2O	—	577	1,300	24	~ 0.234	(As above)	—	11 ft I.D.×32 ft	—	—	569	1,200	—	—	692,100
3	None		H_2O	—	574	1,250	21	~ 0.29	(As above)	Type A 302 grade B steel lined with 304 S.S. 4 in. thick	8.25 ft I.D. ×32 ft	—	—	569	1,200	—	—	692,100
4	—	2 shell and tube type	H_2O	2,533 kg	285°C	70.3 kg/cm² abs	12	19.5%	Cruciform in boron S.S. width 400 mm ; thickness 6 mm	ASTM A-212 Gr, B or A-302 Gr, B steel	2,472 mm× 8,784 mm	Lead and heavy concrete	Steel capsule dia. 23,000 mm height 38,000 mm	246°C	34 kg/cm² abs	—	—	57.85 kg/s
5	.21 MW	2 vertical U-tube steam generators and 2 horizontal straight tube superheaters	H_2O	—	525	935	24	21%	Cruciform absorber blades 0.25 in. thick; 9.3 in. span; boron S.S. with Zircaloy 2 followers	3.375 in. thick SA 212 B steel internally clad with S.S.	7 ft 6 in. I.D.× 24½ ft	Concrete	Steel cyl. 32 ft dia. by 46 ft high	520	500	—	—	153,000 lb/h
6	.27 MW	None	H_2O	—	578	1,300	21	16%	As above but 15 in. span	4 in. thick SA 302 B steel clad internally with S.S.	8 ft 4 in. I.D. ×32 ft	Concrete	Steel sphere 120 ft dia.	574	1,250	—	—	668,000
7	—	—	H_2O	—	530	890	21	0.83%	Cruciform 54 in. long; 0.887 in. wide; blade thickness 0.375 in.	Carbon steel clad with S.S.	74 in.×310 in.	Cylindrical biological	Domed cylinder	528	875	—	—	1.5× 10^3 lb/h
8	—	—	H_2O	—	536	547.6	32	0.75%	Cruciform 82 in., width 8.75 in.; blade thickness 0.375 in.	As above	120 in.×486 in.	Cylindrical biological	Sphere	547.6	1,025	—	—	5.84× 10^5
9	.13 MW	—	H_2O	—	578	1,300	13	22%	Cruciform absorber blades 0.25 in. thick ; 15 in. span boron S.S. with Zircaloy 2 followers	5.12 in. thick SA 212 B steel clad with S.S.	7 ft 7 in.× 25 ft 5 in.	—	Steel cyl. 65 ft dia.× 112 ft high	574	1,250	—	—	401,700 lb/h
10	—	—	H_2O	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
11	.152 MW	One gas to gas recuperator 4-pass counter flow; one gas to air pre-cooler single pass cross flow	H_2O	190 lb in core	185	25	12	5.5 total	Flat blades as six pairs; one pair entering each face of the hexagonal core	S.S. pressure tubes	—	8-in. lead 30 in. borated water as alternate radial layers	—	No steam—direct Brayton cycle gas turbine				
12	3.18 MW	2 water-tube boilers	Grade A graphite	82 t (inc.	425°C	—	15	18%	Boron-steel tube, electrical drive coarse 6 fins	JTA type 101 steel	15 ft 8¾ in. O.D. ×40 ft	Concrete	¾ in. thick cyl. vessel	900	900	—	—	295,000 lb/h

11	.152 MW	One gas to gas recuperator 4-pass counter flow; one gas to air pre-cooler single pass cross flow	H_2O	190 lb in core	165	25	12	5.5 total	Flat blades as six pairs; one pair entering each face of the hexagonal core	S.S. pressure tubes	—	8-in. lead 30 in. borated water as alternate radial layers	—	No steam—direct Brayton gas turbine cycle					
12	3.18 MW	2 water-tube boilers	Grade A graphite	82 t (inc. reflectors)	425°C	—	15	18%	Boron-steel tube, electrical drive coarse 6 fins	JTA type 101 steel	15 ft 8¾ in. O.D. ×40 ft	Concrete	¾ in. thick cyl. vessel 75 ft dia. 140 ft high	900	900	—	—	295,000 lb/h
13	3.4 MW	2 shell and multi-tube	Grade A graphite	680 t	—	—	—	—	—	1½ in. thick low carbon steel	31 ft×54 ft	7 ft concrete	—	690	300	—	—	9.85 lb/kWh
14	2,100 h.p. ×2	2—once through	Beryllium oxide 68,000 lb	—	—	—	25	—	Square array cruciform Dy_2O^3 cermet	SA 302 B low alloy steel	12.3 ft O.D. ×21.3 ft	Concrete	—	900	850	—	—	386,000 lb/h
15	.75 MW	4 U-tube, vertical	D_2O	70 t	220°C	34 at.	27	18%	Rods Ag-In-Cd-tubes clad with S.S. 70 mm thick, type SIS 2103	70 mm thick unalloyed pressure vessel steel	4,555 mm ×4,350 mm	Concrete with iron ore	Underground in sealed building	198°C	15 at.	—	—	30 kg/s
16	2,484 kW	2 U-tube heat exchangers	D_2O	43.7 t	153.5	90 kg/cm²	—	10%	Ag-In-Cd tubes, 20° inclined; magnetic jack drive mechanism	A 302 B carbon steel clad with 18/9 steel	12.8 cm ×780 cm	160–200 cm heavy concrete	Spherical vapour container	L.P.		238°C	33 kg cm²	304.4 t/h
17	800 h.p.	Vertical shell and tube boiler and superheater	Isometric terphenyls	Same as coolant			13	12.2%	Operated singly and in groups of 2 and 3 composite of 48 boron-filled, S.S. tubes; magnetic jack drive	2 in. thick carbon steel	8 ft×27 ft 4 in.	7 ft concrete	⅜ in. steel wall p.v. 70 ft dia. × 125 ft high	550	435	—	—	150,000 lb/h
18	336 h.p.	2 circuits comprising evaporator and superheaters	Terphenyl and associated polymer	—	—	—	31	20%	Boron Steel	1 in. thick M.S. cyl. vessel	8 ft×27 ft	Concrete	1½ in. thick steel cyl. 42 ft dia.	615	600	—	—	—
19	—	1 U-tube, 580 m²	H_2O	—	260°C	141 kg/cm²	12	14%	80% Ag—15% In—5% Cd cruciform cross section	Carbon steel lined with 304 S.S.	1.73 m×5.5 m	1.17 m barytes concrete	Cyl. with spherical lid	244°C	55.9 at.	153°C	30 at.	69.8 52.4 t/h t/h
20	.35 MW	1 steam generator vertical with S.S. U-tubes and carbon steel shell	H_2O	1,720 lb	513	2,000	12	0.271 = 21.8%	5½-in. sq. tubes with 48-in. long absorber and 48-in. long fuel section, stainless steel	5 in. thick carbon steel clad internally	7 ft×21.5 ft	6.5 ft concrete	Vertical cylinder 28 ft dia.× 100 ft high	445.5	375	—	—	180,800 lb/h
21	—	3—shell and U-tube	H_2O	—	500	1,600	12	~ 0.18	Cruciform shape; absorber section; boron S.S.	4⅛ in. thick	6.5 ft×21 ft	—	—	470	500	—	—	235,000 lb/h
22	—	1 vertical shell and U-tube	H_2O	—	415	970	12	~ 0.19 (cold)	Cruciform shape boron S.S. absorber section	SA 212 Gr. B carbon steel	6.5 ft×16.5 ft	Concrete	Carbon steel shell int. press. 30 p.s.i.g.	380	196	—	—	136,800 lb/h
23	—	2 shell-type with U bundles	H_2O	—	586	1,750	32	—	Boron steel rods—cruciform section	Cyl. steel vessel with S.S. lining	9 ft I.D.	Water and concrete	60 ft dia. steel sphere	—	650	—	—	800,000 lb/h
24	.187 MW	1 vertical U-tube	H_2O	—	505	1,750	16	23% cold 28% hot	Boron S.S. cruciform shape.	Carbon steel S.S. clad	81⅝ in. I.D.× 21 ft 9⅝ in.	—	—	470	500	—	—	235,000 lb/h
25	.42 MW	1 vertical U-tube steam generator	H_2O	—	525	2,000	19	10%	Neutron rectifier type water filled absorber box of Ag-In-Cd clad in S.S. with fuel assembly 'follower	4.5 in. thick SA 302 B steel clad internally with S.S.	6 ft 6 in.× 20 ft 5 in.	Water tank and concrete	64 ft×125 ft	470	500	—	—	235,000 lb/h
26	.46 MW	1 vertical U-tube steam generator; 1 vertical straight tube superheater	H_2O	—	604	2,000	19	20%		—	5 ft 5½ in.× 19 ft	Water tank and concrete	34 ft×48 ft	602	615	—	—	296,500 lb/h
27	—	2 shell and tube	H_2O	—	536	1,750	16	—	Boron steel of cruciform section	Carbon steel cyl. clad int. with austenitic S.S.	6 ft 9 in. I.D.	Water and concrete	Sphere 47 ft dia.	497	650	—	—	263,000 lb/h
28	300 h.p.	1 shell and tube	H_2O	7,800 lb	442.4	903	12	20.8%	Square array 10×10 cruciform boron and S.S.	1⅛ in. carilloy TI	61 in. I.D.× 16 ft 3 in. I.H.	Steel and concrete	Cylindrical concrete	455	—	—	—	168,400 lb/h
29	.225 MW	1 vertical U-tube	H_2O	—	503	2,000	12	—	80% Hg; 15% In; 5% Cd	—	58 in. I.D.×18 ft	3 in. S.S. on sides, 3 ft × 10 in. barytes concrete	54 ft×107 ft	472	525	—	—	154,400 lb/h



Gas-cooled
General Atomic



BR-3
Westinghouse Electric

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Gas-cooled
General Electric
Co., Ltd.

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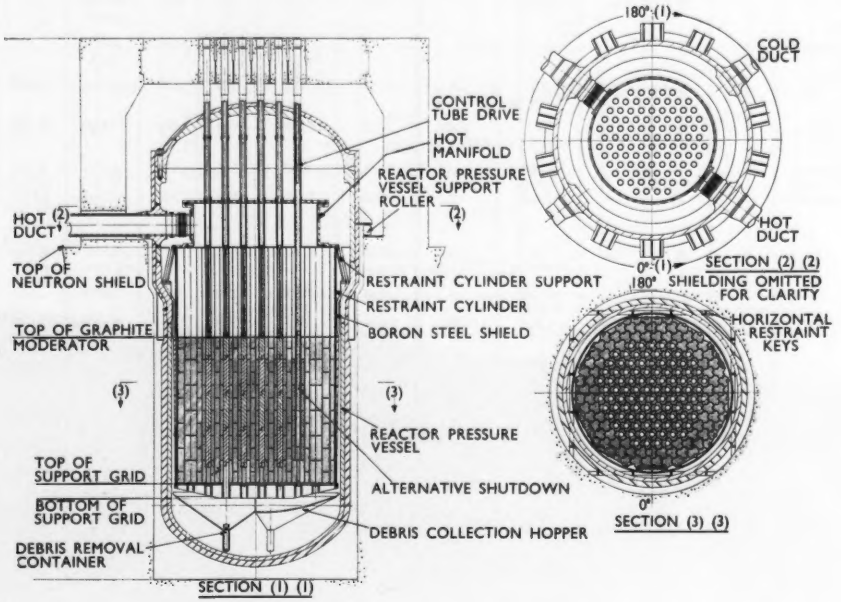
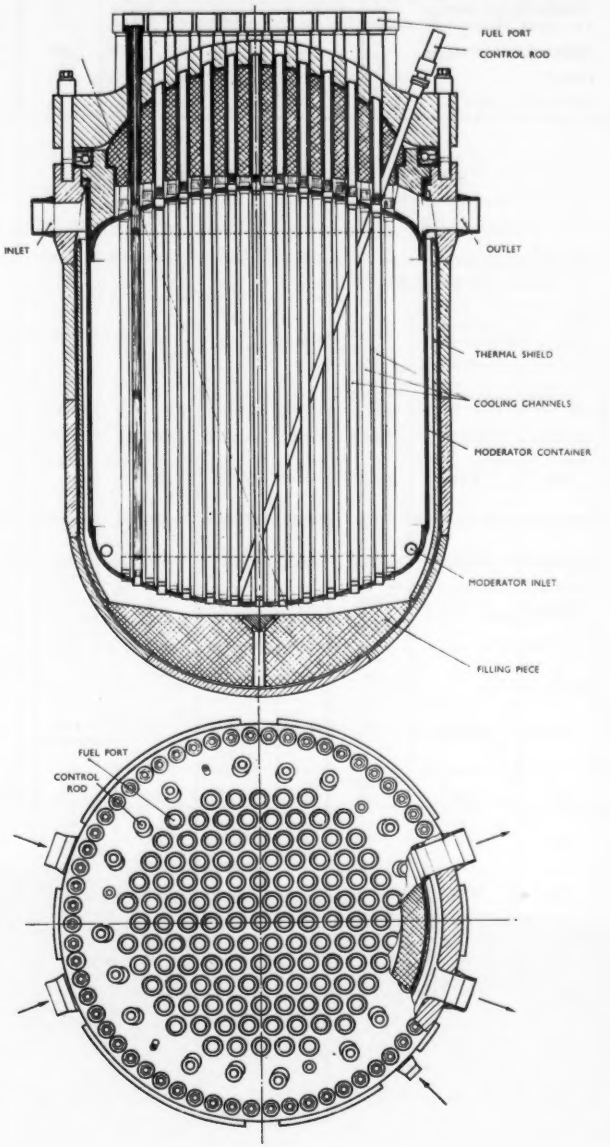
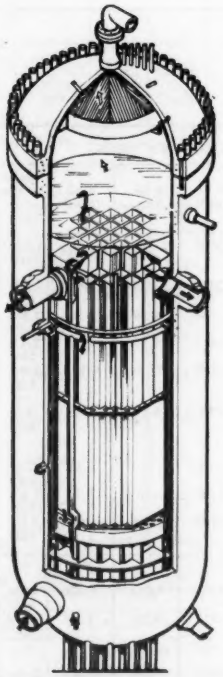
D_2O
Siemens-Schuckertwerke

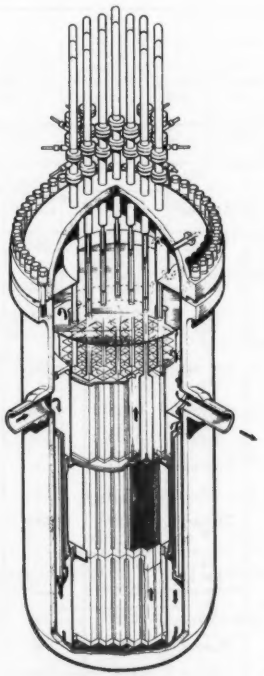




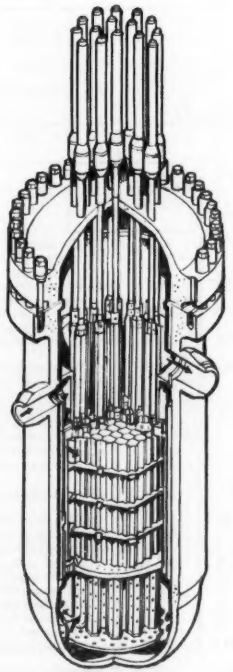
SMALL AND MEDIUM POWER REACTORS



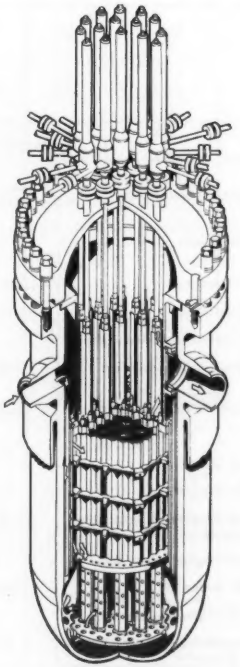
ICB-S1
Combustion
Engineering



DCB-M2
Combustion
Engineering



P-S1
Combustion
Engineering



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RADIATION DOSIMETRY

The Vienna Symposium

reported by **K. F. ORTON, B.A. (Cantab.)**
(Head of Radiation Section, APD, The English Electric Co., Ltd., Wheatstone)

UNDER the auspices of the IAEA, a symposium on selected topics in radiation dosimetry, held in Vienna from June 7-11, produced some 75 papers, arranged in five main groups:—

Problems related to exposure and absorbed dose; new developments in dosimetric instrumentation and methods; dosimetry for mixed neutron-gamma radiation; special methods for dosimetry of radiation from accelerators or reactors; dosimetry on critical assemblies.

The conference opened with general survey papers by K. Z. Morgan (Oak Ridge) and Dieval (Saclay). Dr. Morgan discussed the general downward trend of maximum permissible levels during the past 25 years and then reviewed briefly the available instruments and discussed the characteristics of good instruments. In all, Morgan listed 24 points which should be borne in mind when designing health physics instruments and his paper should be of interest to all who are concerned with this problem. Apart from the purely instrumental features such as accuracy, stability, zero drift, directional response, etc., Morgan stressed the importance of measuring absorbed dose (in soft tissue) and of responding to only one type of radiation at a time.

With the reduction in the weekly permissible levels for external radiation Oak Ridge have found it desirable to process film badges over 13 weekly periods resulting in an error on the annual dose of ± 0.12 rad, as it has been found that reading errors of ± 30 m rad occur in routine procedures using technicians to process the badges. The adoption of such long periods means that persons likely to receive measurable exposures must be provided with pocket dosimeters which can be read daily.

Finally, Morgan reviewed the outstanding problems in health physics and here he mentioned the following points.

(1) The fact that several instruments may be required to cover the range of dose rates required, i.e., film badge plus pocket dosimeter.

(2) A measurement of absorbed dose is not sufficient for health physics purposes—the fractionation of the dose into neutron and gamma components is necessary to establish biological dose.

(3) The measurement of the spectrum of radiation—in particular the measurement of neutron spectrum is important as Snyder has shown that this is necessary to evaluate the maximum biological dose in the body.

(4) The effect of angular distribution of radiation on the response of meters and on biological damage.

(5) The importance of dose rate is not fully understood.

(6) The need for better dosimetry of ingested and inhaled materials.

(7) The need for more and better instrumentation for emergency exposure.

Dieval discussed the radiation protection problems which arise in industry and, after reviewing the general principles applicable in laboratories and plants handling radioactive materials, described equipment which had been developed at Saclay. It was stressed that health physics instruments should be portable and self contained, inexpensive, employ simple working parts, and be easily maintained.

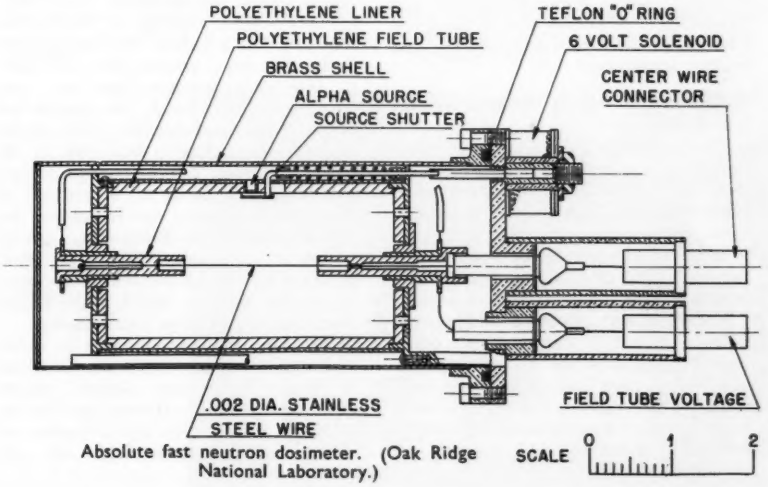
Exposure and Absorbed Dose

Neufeld (ORNL) opened the session on exposure and absorbed dose problems with a paper describing recent calculations of LET (linear energy transfer) in which the LET is expressed as the summation of terms due to elastic and inelastic collisions. This work is the basis for establishing the maximum permissible fluxes for fast neutrons. Otlet (AERE) reported on the use of condenser chambers for measuring exposure dose and Allisy (France) described a method of measuring absorbed doses in bone and muscle using ionization chambers filled with air-argon mixtures.

Prof. Sievert (Stockholm), who had taken the chair at the opening session, drew attention, in his paper on a personal recording dose-rate meter, to the fact that personnel monitoring is normally carried out with integrating dosimeters such as condenser chambers or film badges. There are reasons to believe that dose rate may be an important factor biologically as well as total integrated dose, and, apart from this, there are many advantages to be gained from a knowledge of the dose rates to which personnel are exposed. Such knowledge is invaluable in attempting to reduce exposure to a minimum. In an instrument described by Prof. Sievert, dose rate records are presented on a rotating disc, 1 in. diameter, using a logarithmic scale. A resolving power of the order of a few seconds has been obtained and the sensitivity can be adjusted over a range of about 10^7 in dose rate. Visual inspection shows immediately whether the dose rate has changed and more accurate information can be obtained by viewing the trace under a microscope.

Jonckheere (Belgium) described the use of electrometer triodes with logarithmic response over 6 to 9 decades and accuracies of better than 3%. The ME1401 and 4065 tubes can be used over 6 decades but the use of the ET3 enables 9 decades to be covered. A twin condenser chamber has been developed by Walstam (Stockholm) to cover a wider range of integrated dose than is possible with a single chamber. Two concentric chambers are used with volumes in the ratio of 10 : 1 and in a typical case the ranges covered are 20 to 200 m rad and 200 to 2,000 m rad respectively.

An interesting condenser chamber has been used by Bozóky (Budapest) for measuring doses in the range of 50 to 10^4 rad. The chamber is sealed in a glass envelope under reduced pressure and no permanent connection is provided for the collecting electrode. Charging and measurement are effected by operating a magnetic switch inside the chamber thus connecting the collector to an auxiliary electrode sealed in the wall of the



Absolute fast neutron dosimeter. (Oak Ridge National Laboratory.)

container. A special design of air space ensures a linear response and, if required, the chamber may be immersed in water with no ill effects.

Other papers in this session dealt with ionization recombination losses (Loevinger, U.S.A.), errors due to the finite size of chambers in depth dose measurements (Lidén, Sweden), saturation effects with pulsed beams (Allewaert, Belgium) and ionization chambers for Grenz rays (Tranter, U.K.).

In a session devoted to scintillation devices Forte (Italy) described recent developments on particle discrimination according to specific ionization, work which is of particular interest in obtaining scintillation detectors with high neutron, and low gamma, sensitivities. Trouble (Saclay) showed that a plutonium detector, based on measuring the 17 KeV gamma ray with a thin NaI crystal, could be used to pick up contamination in or near the skin surface, and Orton (U.K.) by considering single scattering collisions, described how pulse height distributions in organic phosphors could be interpreted.

Wachsmann (Germany) reported on the system of photographic dosimetry for personnel monitoring employed at Erlangen. Several copper filters of different thicknesses are used and, with two films, of different sensitivities, in a single packet, doses ranging from a few m rad to about 1,000 rad may be measured. Hunzinger (Switzerland) uses filters of rhodium plus lead, tin plus lead, and plastic, and the blackening under these filters, together with the blackening under an open window, enable the beta, gamma and thermal neutron doses to be evaluated.

There is considerable interest at present in chemical methods of dosimetry and this was reflected in a group of papers dealing with this subject. Minder (Switzerland) has used the Fricke dosimeter for the measurement of photons from 14 keV to 31 MeV and has also investigated the dosimetry of mixed beta-gamma radiation from Rb^{86} with this technique. Sigoloff (U.S.A.) described a system using tetrachlorethylene for measurement of gamma dose in the range 5 to 5 x 10^6 rad with a relatively low fast neutron sensitivity.

Dosimetry for Mixed Neutron-Gamma Radiation

The sessions on the dosimetry of mixed neutron and gamma fields proved to be some of the most interesting of the whole conference. The importance of measuring these components separately had been stressed by Morgan at the opening session and it was obvious that this is a field in which there is a great deal of activity.

Moteff (USA) reviewed the present status of threshold and resonance detectors—techniques which are almost completely free from gamma response—and Davis (USA) described the Hurst dosimetry system which uses Pu+B^{10}, Np^{237}, U^{238} and S^{32} as threshold detectors for evaluating the biological dose.

The Radsan, a tissue equivalent, proportional counter can be used for the measurement of fast neutron dose rates in high gamma fields. Hurst (U.S.A.) showed that neutron dose rates of 1 m rad/h may be measured with this counter in a gamma field of 25 rad/h by adjustment of the discriminator bias. It was shown how corrections for the fraction of neutron dose lost under the bias could be estimated—in the case quoted this is about 18%. In reply to a question it was learnt that this instrument will be available commercially by the end of the year. The British fast neutron counter was described by Dennis (AERE). This is a proportional counter with a polythene wall and a methane-argon gas filling and the response may be adjusted to within ±20% of the ICRP biological response curve.

Neary (M.R.C.) reported on the chambers which had been designed at the Radiobiological Research Unit at Harwell for the estimation of neutron dose in the chronic irradiation experiments. A CH plastic, acetylene filled, chamber has been used and the response of this chamber has been compared with a Rossi tissue equivalent chamber at Berkeley and Harwell, and with calibrated fast neutron beams at Los Alamos. Discrepancies of up to 20% were found, but these can be reduced if it is assumed that W (energy per ion pair) is constant.

The necessity for international intercomparisons of neutron detectors and sources was stressed by Wheatley (CERN) in the discussion which followed and the Agency was asked to undertake the organization of this work. Prof. Jaeger (IAEA) accepted this request on behalf of the Agency and it is to be hoped that this work will lead to a more satisfactory basis of neutron dosimetry.

Solid State Dosimeters

The past few years have seen the development of solid state devices as radiation detectors. Attix (U.S.A.) described preliminary experiments on induced photoluminescence in anthracene and showed that, although satisfactory results could be obtained with thick ($\frac{1}{32}$ in.) wafers, attempts to incorporate thin (10^{-4} in.) wafers in a Bragg-Gray device had been unsuccessful. In order to investigate whether there was any unforeseen limitation on the application of the Bragg-Gray relation, Mylar (polyethylene terephthalate) was used as the sensitive element and the change in optical density measured as a function of dose. In this case it was found that the device obeyed the Bragg-Gray theory. Moreover, it was discovered that, although Mylar did not exhibit any optical fading, Melinex, which is the British brand, showed a large initial fading.

Work on photoluminescence in silver-activated phosphate glasses was described in papers by Yokota (Japan), Auxier (U.S.A.) and Kondo (Japan) and the use of these detectors in the dosimetry of mixed neutron-gamma fields was discussed.

Thermoluminescent techniques were the subjects of papers by Attix (U.S.A.) and Schön (Germany) and improved dosimeters using specially prepared manganese activated calcium fluoride, operating over a range of 0.005-10^4 rad, were described. The use of perforated tin shields produces a dosimeter with little energy dependence and the simplicity of the device and its linearity over seven decades, make it ideally suitable for use in accident monitoring. The storage loss which occurs results in an uncertainty of ±8% over a period of a fortnight, and ±15-20% over a 30-day period—but the limit of sensitivity is so low and the dosimeter so easy to read that shorter monitoring periods can be used with advantage.

Radiation Dosimetry for Accelerators and Reactors

Wheatley (CERN) and Wallace (Berkeley) discussed the health physics problems associated with high energy accelerators. Various techniques were described including the use of thermal detectors surrounded by a hydrogenous shield to measure the number flux of fast neutrons, polyethylene lined proportional counters to measure the energy flux, the use of the C^{12} (n, 2n) C^{11} threshold reaction by irradiating large plastic scintillators, and Wallace mentioned the use of a bismuth fission chamber with a threshold of 50 MeV. Humbel and Stebler (Landis and Gyr) described a tissue equivalent dosimeter designed for use at CERN, and Cowper (Canada) described some of the techniques which had been developed at Chalk River for controlling radiation exposures.

A report was given by Linacre (AERE) on calorimetric measurements carried out by himself and Anderson on a wide range of materials in BEPO and DIDO and Aleksandrowicz (Poland) described how he had used the change in electrical conductivity of germanium under fast neutron bombardment to investigate the flux distribution within a reactor core.

Dosimetry on Critical Assemblies

In the final session of the conference Snyder (U.S.A.) discussed the need for knowledge of dose patterns within a body exposed to fast neutrons. After describing the results of calculations in which the absorbed doses from monoenergetic neutron beams were obtained as a function of depth in infinite slabs of tissue, 30 cm. thick, Snyder dealt with the estimation of induced Na^{24} activity as a function of neutron energy for a cylindrical standard man. The variation of RBE with energy and with depth was demonstrated and calculations show how some organs are irradiated by radiation of a different RBE from others. Interpretation of experimental work will require the type of detailed consideration outlined above.

The proceedings of the symposium will be published towards the end of the year by the IAEA and copies may be obtained through HMSO.

INTERNATIONAL MEDICAL ELECTRONICS EXHIBITION

OLYMPIA, JULY 21-27

Winston Electronics' stand.

NEARLY one third of the exhibitors at the International Medical Electronics Exhibition held at Olympia during July incorporated some type of linear accelerator, radioactive measuring equipment, radioisotope scanner, etc., in their exhibits. Some 60 companies were represented all told of whom 20 came from overseas.

The exhibition was held in conjunction with the Third International Conference on Medical Electronics and included a session on isotopes. Lectures and contributions included reactor applications to brain tumour radiation, applications of counting methods during radioisotope therapy and brain tumour localization, and therapy by positron scanning.

Main exhibitors were:

Alvar Electronic (Paris) showed a Gammaencephalograph for brain diagnosis by isotopes and a Cathograph, a camera for photography of electrophysical phenomena on one or several cathode ray tubes.

AEI's Instrument Division had on display models of the Orthotron 4.3 MeV linear accelerator for supervoltage therapy and the Obitron cobalt-60 therapy equipment. Demonstrations were given of the pulse height analysers PHA.2 and PHA.3, instruments for sorting complex radiation spectra into channels of known amplitude. The PHA.2 has a capacity of 70 channels each counting up to 1 million pulses or 100 channels counting 16,000 pulses and the PHA.3 incorporating transistors has 100 channels with a capacity of 65,535 pulses.

The **AEA's** Weapons Research Establishment showed equipment for measuring radioactivity ingested by the body, probes for detecting material in wounds and for monitoring contaminated surfaces and simple counting instruments.

I. G. Bailey's stand included the new Westminster Hospital two-stage cooling apparatus for the controlled cooling of bone marrow in connection with research into the causes and cure of the effects of radiation during treatment of cancer.

Measuring instruments by **Baldwin Industrial Controls** included the Ionex, an instrument for measuring dose and dose-rate of ionizing radiations over a wide range and an X-ray dosemeter for routine measurements. Radiological densitometers for personnel subjected to radiation were also on display.

A comprehensive display of instruments incorporating isotopes were shown by **Ekco Electronics** including a working demonstration of thyroid activity measurement and equipment for brain tumour location. A new portable radiation monitor was shown with a field ratemeter with a range of alternative counting heads. Laboratory equipment included a complete gamma spectrometry installation, a vibrating reed electrometer and a range of scintillation crystals. For the rapid assay of samples a new automatic scaler has been produced in which the timer can be adapted for use as a second scaler with built-in discriminator.

A stand by the **Electronic Industries Association of Japan** represented 11 major companies.

Electronic and X-ray Applications showed a Picker complete radioisotope scanning system and a proportional flow counter for windowless operation.

Among **English Electric Valve's** display of a wide range of specialized electronic valves and tubes were cathode tubes, oscillators and high-power magnetrons and klystrons for linear accelerators.

A comprehensive foreign exhibit by **Frieseke and Hoepfner** (Erlangen Bruck, Germany) included radiation measuring instruments, lead shields, ionization chambers, radiation monitors and a mobile radiation laboratory.

New developments in image amplifiers were demonstrated by **Marconi Instruments** in their 12-in. type which incorporates a brighter screen image but subjects patients and radiologists to less radiation.

Mullard Equipment demonstrated a scale model of a 4 MeV linear accelerator, a unit-built hand and clothing monitor, gamma alarm monitor and a range of Geiger-Muller tubes. Examples were also displayed of quartz fibre dosimeters and ultrasonic cleaning equipment.

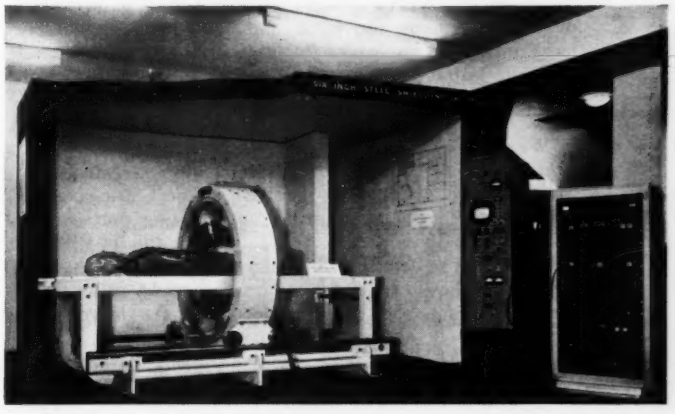
A wide range of interesting apparatus was exhibited by **Nuclear Enterprise,** including a human body monitor for gamma ray spectrometry with high energy resolution, a tritium, carbon-14 counting assembly and a full range of scintillators. An extensive range of geometries is now available in the NE102 polyvinyltoluene plastic scintillator from thin sheets to large slabs. Pulse height is quoted as 65% of that of anthracene slow neutron detectors containing enriched boron and using a currogated surface for improved efficiency were also on view.

Picker International's stand included a well counter designed to reduce background count with easy decontamination and a proportional flow counter with windowless or with an ultra-thin window for background detection of soft beta radiation.

RCA International of New Jersey showed among other things oscilloscopes, and cathode ray tubes.

A mock-up of a steel room designed to provide low background for human body counting was displayed by **Saunders-Roe and Nuclear Enterprises.**

Among **Winston Electronics** comprehensive display was a Beryllium monitor (see Process and Equipment, page 421) oscillators and general purpose laboratory test equipment.



A human body monitor for gamma ray spectrometry by Nuclear Enterprises for shipment to Australia.

Third Party Liability Convention

Five First Signatories to OEEC Rules

FOLLOWING the many months of discussion between the varied parties concerned with the liability aspects of nuclear installations, including potential reactor operators, government representatives, insurance organizations and industrialists, OEEC's convention on third-party liability in the field of nuclear energy has been completed and signed by five contracting parties, the minimum number to bring the convention into effect. The first signatories were the U.K., Denmark, Luxembourg, the Netherlands and Switzerland. Other governments who have not yet ratified the convention will be able to do so up until October 31 this year.

The convention is an important contribution to international law as its clauses are specific and its coverage wide. It is not completely comprehensive and in particular it avoids the subject of marine nuclear insurance and the implications of nuclear-powered aircraft, but so far as land-based stations are concerned it caters for all aspects of construction, operation and the transport of fissile material to and from the establishment.

In many respects the convention follows the liability section of the Nuclear Installations (Licensing and Insurance) Bill applicable in the United Kingdom but it is more far reaching, particularly on the thorny problem of transporting nuclear materials across and through contracting and non-contracting States.

The convention has contrived to define the plants and organizations coming within its terms of reference somewhat more elegantly than the U.K. Bill. A distinction in terminology is that between "nuclear fuel" which covers all fissionable material (and therefore natural uranium) and "nuclear substance" which is specially defined to exclude natural uranium or depleted uranium. The completed convention is designed to cover establishments within the territory of contracting parties where a critical mass can conceivably be assembled or where fission products in quantity are being treated or disposed of. Research establishments employing radioisotopes, subcritical assemblies of natural uranium, or accelerators, and fuel element production factories for natural uranium are excluded.

As in the Licensing and Insurance Bill great importance has been placed on defining the body responsible for the installation and there is a slight change in terminology from owner (licence holder) to operator. The principle, however, remains the same and the change is largely academic. The important feature is that the operator has absolute liability but up to a defined amount for which proper financial coverage in terms of assets or insurance must be arranged.

Where nuclear material is being transferred from one installation to another, the exact point at which the responsibility changes is specified. Where transport is wholly within the territories of contracting parties (i.e., nations who have signed the convention) this is straightforward and is determined by the point at which the new operator takes over but complexities could arise if no specific ruling had been made when the material is travelling to or arriving from an outside country. In the first case the operator in the contracting party carries the responsibility until the material has been transferred from the means of conveyance which carried it to the outside territory. For incoming material the operator takes over the moment that it is loaded aboard the conveyance leaving the outside territory.

It is recognized that national legislation may permit the transfer of responsibility to the carrier himself, in which case proper financial coverage must be demonstrated by the carrier concerned and in the case of any subsequent actions he takes the place of the operator and assumes the same liabilities. National law may also permit the direct action of claimants against the insurer instead of via the operator.

If a nuclear incident occurs in an area under the jurisdiction of a non-contracting State, or there is damage there, a company with its principal place of business in the territory of the contracting party (or one of its employees) may claim against the operator who would have been liable if the State had been a party to the convention but only up to the limits of amount laid down. The council may decide to extend this privilege to carriers whose principal place of business is not in the contracting State dependent upon circumstances.

The limits required for third party coverage are set at a minimum of 5,000,000 European Monetary Agreement units and a maximum of 15,000,000. The upper limit is regarded as necessary to avoid unduly restricting the development of nuclear energy but governments will in many instances give guarantees over and above this amount; (in the United Kingdom each case will be treated on its merits by Parliament).

The liability of the operator continues for 10 years after the date of the nuclear incident and claims must be tabled before the end of this period, or at least appropriate court action sought, for them to be valid. In the case of lost, stolen or abandoned materials the figure may be reduced by national legislation to two years from the date at which it is reasonable for a claimant to have known that the incident occurred and provided that this does not exceed the 10 year period from the actual date. Acknowledgment is given to the fact that national legislation may establish a longer period in which claims can be lodged (in the United Kingdom 30 years) but the liability of the operator himself is limited to the 10 year period. It should be noted also that where incidents form part of a national catastrophe arising from war or a grave natural disaster of exceptional character then the liability must assume a national character and be handled by the Government rather than remain with the operator.

The convention came into force when the five signatories deposited instruments of ratification and for signatories ratifying thereafter the convention will apply immediately. Amendments will require the mutual agreement of all the contracting parties and will come into force when ratified or confirmed by two-thirds of the members. The convention is to remain in effect for a period of 10 years as from the date of its coming into force, but by giving 12 months' notice any contracting party may terminate its association at the end of this period. The convention will be kept in force for a further five years for parties who have not withdrawn and thereafter for successive periods of five years as may be necessary.

Aluminium Welding and Manipulation

—*Swedish Methods*

By ING. U. ALFREDSSON

The methods employed in aluminium welding by Svenska Metallverken are discussed in this article. This concern specializes in aluminium welding and manipulation and have done extensive work at the Studsvik nuclear centre in Sweden and also work at Petten in the Netherlands and for Fabricom, Belgium.

ALUMINIUM is in many respects an excellent material for nuclear applications. In addition to being easy to work and shape at moderate temperatures, it has good resistance to corrosion. It also has the advantage of low neutron absorption and a short half-life and is a relatively inexpensive material. The first requirement for making components of the highest nuclear quality is that the material itself should be of the best quality. It does not suffice merely to ensure that alloying elements are added in the required quantities. Great care must also be taken to keep impurities within definite, extremely low limits.

Pure aluminium IS has been chosen for instance in the reactor vessel and in the storage tank for the RO reactor. In general the stresses are much higher in the R2 reactor and for this reason aluminium alloys with good mechanical properties have been used. All the smaller dimensions of pipes, from $\frac{5}{8}$ in. to 10 in. diameter, have been extruded in the Al-Mg-Si alloy 50S. Another alloy of the same type is 65S which has been used for flanges and for pipes larger in diameter than 10 in. The reason why 50S has been chosen for the smaller pipes is that in addition to having good corrosion resistance, it is also suitable for extrusion. Pipes over 10 in. diameter have been welded from plate and as the strength in the joints is slightly reduced the stronger alloy 65S has been used. Both 50S and 65S can be solution heat treated and artificially aged.

Checking a mitred elbow.

Dual operator welding.

The pool liner, decay tank, storage tank, heat exchangers and the lower outlet from the reactor vessel have all been made from the alloy 57S which has good mechanical properties and high resistance against corrosion. Combinations of different alloys have been used on many places in the piping systems, tanks and heat exchangers.

The RO Reactor Tank

The tank is 90 in. in diameter and 128 in. high. The shell is $\frac{1}{4}$ in. thick and the conical bottom has $\frac{3}{8}$ in. plate thickness. Close tolerances were necessary on the completed tank and proved difficult to attain. The requirement was that the circumference measured on any level of the tank was allowed to vary only within about 1 mm (about $\frac{1}{32}$ in.) and the out of roundness, i.e., the tolerance on the inside radius, should not be more than about 1 mm. Special tools had to be designed and installed into the tank to enable exact measurement on all levels and 256 measuring points were carefully registered and the small deviations were noted within 0.0004 in. Thus in the radiographic calculations and measurements, which in the future will be made by use of the reactor, allowance can be made for those small deviations of the tank radius.

The Lower Outlet from R2

The lower outlet is bolted to the bottom flange of the reactor vessel and the joint is tightened by means of an aluminium gasket. The dimensions are: Height 88 in.; diameter all over 100 in.; diameter of upper flange 85 in.; thickness of upper flange $3\frac{1}{2}$ in. The shell thickness in the upper part is $1\frac{1}{4}$ in. and in the lower one $\frac{3}{4}$ in. The tolerance requirements are high. The upper flange had to be flat within 0.005 TIR and perpendicular to the centre line within 0.005 TIR.

Owing to the great plate thickness, the welded joints had to be rather thick and it took a considerable time to weld the $3\frac{1}{2}$-in. thick flanges, particularly as X-ray examination had to be carried out after each pass in the joint. This precaution was taken in order to ensure that no cracks or pores would be built in. When such an amount of heat is transferred to a material as was the case when welding the biggest joints, special care had also to be taken to prevent shrinkage and to keep the rather small

tolerances. Thus, the big flanges were bent before the welding in order to get them plain afterwards. For the welding of the lower outlet 540 lb of filler rods and over 8,000 cu. ft of argon gas were used.

The R2 Pool Liner

The largest aluminium part in the Studsvik plant is the reactor pool liner. Roughly 110,000 gallons of demineralized water can be kept in the pool, the dimensions of which are: Length 61 ft, width 10 ft and height 30 ft. All sidewalls are made of sheet ¼ in. in thickness and are strengthened by vertical T-profiles which are welded to the liner. Besides supporting the walls during the erection the tees also help to keep the sides tight to the concrete. The pool liner is divided into three different parts by means of gates which can slide up and down in guides. Each gate must be constructed to allow no water leaks even if one part should be empty at the same time as one is filled with water.

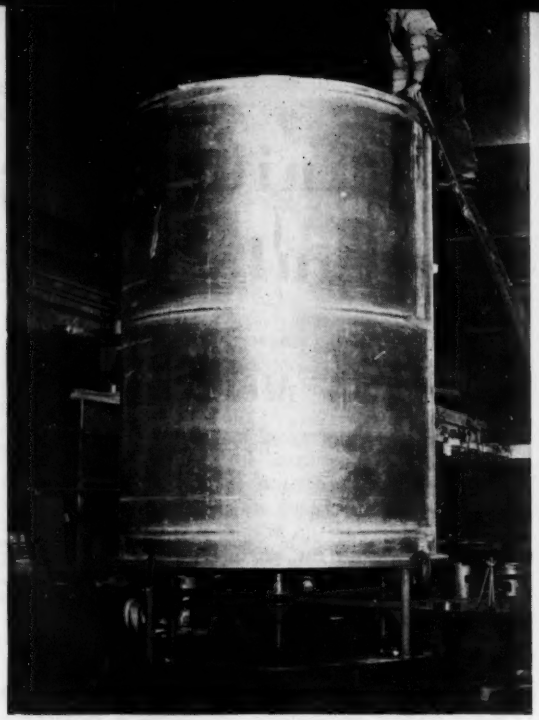
R2 is placed in an arrow-shaped pool. The pool wall has 10 horizontal beam tubes, a large experimental facility and a number of other experimental facilities of various sizes. The middle part is a storage pool and the third part contains a small experimental reactor R2-0. The aluminium used for the pool liner weighs about 21 tons.

The R2 Piping System

The whole piping system is built up from straight pipes, elbow reducers, tees, nipples, couplings, etc., which have been welded together in the workshop to certain erection units and sent to Studsvik and then welded into tight piping system. At the time this work was being undertaken Svenska Metallverken made no standard fittings for nuclear use and forged aluminium fittings for the purpose were not available in Europe. A plant to manufacture them was therefore established.

All elbows up to 10 in. in diameter have been bent from extruded pipes with the walls somewhat thicker than the matching straight tubes. After the bending the walls are thinner at the outside and thicker at the inside but the tangent walls remain unchanged. Consequently the wall thickness of the elbows has been chosen so that the thinnest portion after the fabrication will be the same as for the ordinary straight pipes. Another reason for bending the elbows is that the calculation of strength shows that the greatest stresses occur at the inside wall of a bend so the inside ought to be thicker.

The lower outlet from R2.



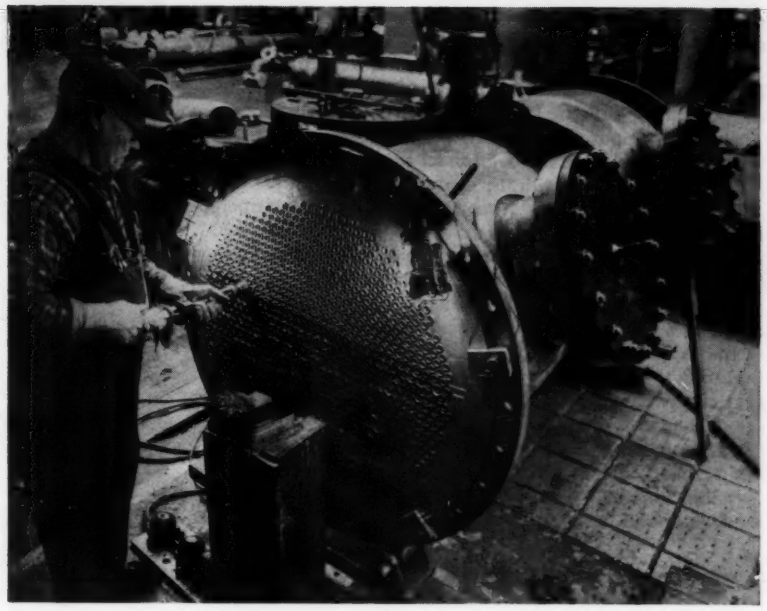
The tank for the RO reactor at the Studsvik research centre.

Some problems had to be solved during the manufacture. Elbows could not, for instance, be fabricated in the usual manner by filling the straight material with sand, resin or other materials, nor could ordinary steel mandrels be employed. Such materials might easily leave impurities in the inside, or cause grooving. Special methods were, therefore, developed, which absolutely ensured that no foreign particles became rolled into or were otherwise incorporated in the aluminium during the fabrication. Elbows over 10 in. in diameter were mitred. The tees were made of straight pipes which were welded together. The welding joints had been designed so that full root penetration was ensured.

All flanges were of the slip-on-welding-plate type with full gaskets covering the whole flange surface. The flange calculation had been made according to ASME code. All erection units were controlled and pressure tested before leaving the workshop.

Tanks

The decay tank has a capacity of 9,250 gallons and a weight of 7,200 lb. The diameter is 8 ft, the length 32 ft and the plate thickness ½ in. Inside are a number of baffles and also a screen. When the water from the reactor passes through the decay tank the velocity is suddenly reduced and the radioactive impurities which might have been entrained in the water have time to settle in the tank. The two demineralized water storage tanks each have a capacity of 22,000 gallons and a weight of 8,500 lb. The diameters are 10 ft, 40 ft in length, and the plate thickness is ½ in. The two tanks together will be able to store the water from one of the three parts of the pool. They are of conventional design, and are placed upon concrete saddles.



Final cleaning of the fixed tube bundle heat exchangers. They are double-clad with a Zn-alloy and have double tube sheets at each end.

R2 Heat Exchangers

The heat exchangers are of the fixed tube bundle construction and have double tube sheets at each end; the tubes and tube sheets are double-clad with a Zn-alloy. The demineralized water passes outside the tubes and the brackish sea-water from the Baltic Sea inside the tubes. Sacrificial zinc plate corrosion eliminators have been inserted into the heads of the exchangers to compensate for any electrolytic action from the sea-water.

Shop and Erection Work

In order to obtain the necessary quality in the welds the following requirements had to be met:

1. No cracks were allowed.
2. No lack of fusion, no oxide inclusions and no undercuts were allowed.
3. No impurities of any other metal could be tolerated.
4. No pores greater in size than $\frac{1}{16}$ in. could generally be allowed and the porosities should be judged according to the porosity charts in the ASME code.
5. A smooth surface without ridges or drops, particularly on that side of the weld where the active medium is, should be obtained.

Before the welding could start a certain amount of preparation had to be completed. The different pipes had to be manipulated to roundness and to the right inside diameter. Joint preparation was also of importance. All edge preparation had to be undertaken with clean tools free from grease. Oil or grease could not be used as lubricants when machining the edge as they penetrate into the surface of the metal and are very difficult to get rid of. Various edge preparations used at Studsvik are indicated on Fig. 1.

Welding Methods

The welding methods used were the inert-gas-shielded tungsten arc process (TIG) and the inert-gas-shielded metal arc process (MIG).

To ensure a good quality of weld the best possible base material was used. Likewise the filler metal had to be of such a composition that optimal weld quality was obtained. As mentioned before the joint preparation and calibration had to be very carefully done in machines specially designed for the purpose. The welding surfaces were cleaned in such a manner as to be completely free from oil, dirt, scale, and other impurities or material which might have been detrimental to the quality of the weld. When welding thick material a thin root run was usually laid by the inert-gas-shielded tungsten arc method (TIG) and the subsequent passes sigma welded (MIG). Pipe welding was done by the TIG method and the U-shaped edge preparation was used.

Site Welding

When welding at the erection site, where the conditions generally were unsatisfactory, extraordinary procedures were necessary in order to obtain welds in overhead positions free from defects. A suitable procedure was to increase the argon shield by using a large gas nozzle. The welding of the pool and the tanks was to some extent made by dual-operator welding, with two operators working simultaneously on each side of the wall, one adding filler metal and the other controlling the penetration. Prior to welding, the joints were first cleaned and then, just before welding, the oxide film was removed by brushing with stainless steel brushes. Although the filler material was kept in tightly sealed packaging from the time of delivery it too was cleaned immediately before use.

Clean air conditions were enforced during welding and the electrical and other equipment were inspected and checked continually and samples were taken of the argon gas. No backing rings whatever, even of stainless steel, were used. There was thus no danger of foreign metal particles remaining in the weld. This danger could have been avoided by the use of aluminium backing rings, but they were difficult to remove, and naturally could not be left in the pipe as they would impede the flow. Instead, a very thin sealing run was made at the root of the weld, to serve as support for the following runs. The thin first run meant that there was only slight penetration at the

root, and the reduction in cross-section was therefore negligible.

As Svenska Metallverken produces the material in the form of tubing and sheet an exceptional degree of quality control can be exercised during all stages of manufacture. The exact composition of a melt can thus be determined within minutes by means of a direct reading quantometer, and altered to accord with the guaranteed analysis.

In order to make welds of nuclear quality, it is extremely important that the metal itself should be free from dissolved gases. Before the material is delivered, with a test certificate to the welding shop, it is subjected to an exacting procedure of control and cleaning. Subsequently it is carefully protected against dirt and damage while in store at the factory.

During the welding all runs are radiographed before the next run is deposited, where the quality requires. If there are defects in the form of cracks, porosity, inclusion, poor penetration, non-joining, etc., the faulty part is chiselled out and rewelded before further runs are made.

As has already been mentioned extremely careful cleaning is essential when turning out first-class products for nuclear or any other exacting application. To avoid getting oil and dirt on the material, the workmen who are handling it wear gloves. Equal care is observed during the final cleaning before delivery from the workshop. The following cleaning steps are taken:

1. Chipping, grinding, and wire brushing with stainless steel brushes to remove all scale, dirt, slag, and other foreign particles.
2. Brushing and vacuum cleaning of all surfaces.
3. Flushing with filtered tap water.
4. Steam cleaning.
5. Air drying with dry, oil-free air.
6. Flushing with trichloroethylene.
7. Air drying with dry, oil-free air.

The last step is followed by sealing in plastic covers to protect the individual parts while in storage.

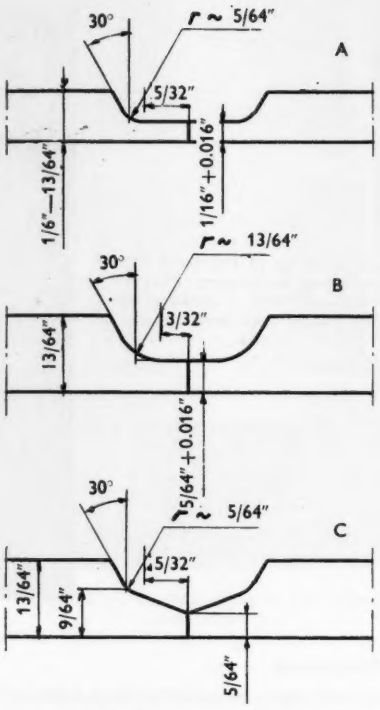


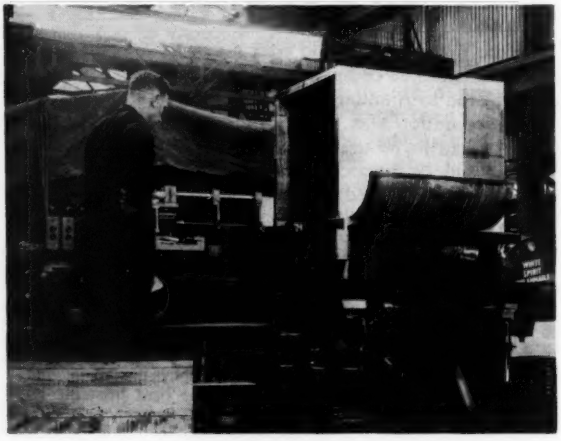
Fig. 1.—Examples of edge preparation.

Automatic welding of a large diameter pipe.

Deep Drilling The R2 Core Tank

The tank of the R2 research reactor for Studsvik, Sweden, is now being constructed at APV's Crawley (Sussex) works to the order of the Allis-Chalmers Manufacturing Co. As the accompanying photograph shows, this job required the drilling of 156 holes $\frac{1}{16}$ in. diameter and 42 in. deep down through the edge of the 2 in. NP5 aluminium plate forming the core box. This extremely difficult operation has been completed by adopting a method used in America for gun barrels.

The drill used has a special cutting head and operates at high speed with a jig supporting its free length. The drill is cored to allow oil at high pressure to drive out the powder swarf. It will be appreciated that a break at this depth would be disastrous.



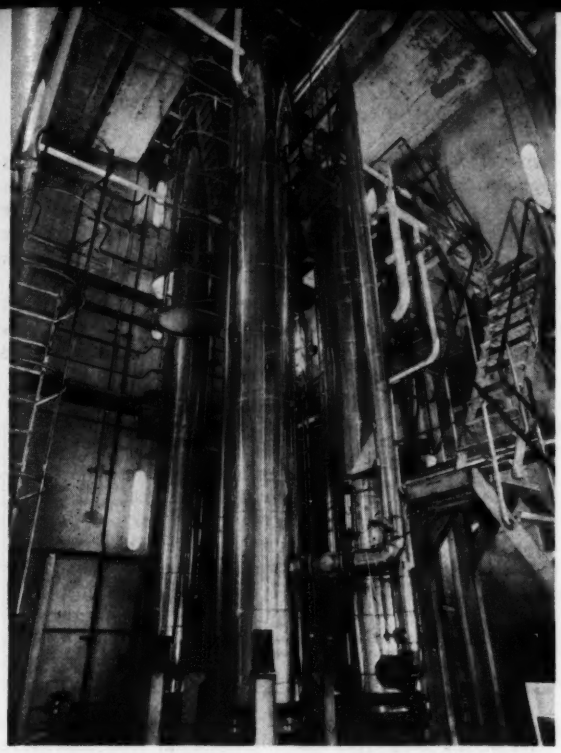


Fig. 1.—ASEA'S second pilot plant for heavy water production.

Heavy Water Production in Sweden

by **BENGT J. ERIKSSON**

(Chemical Engineering Section, Nuclear Power Dept., Allmanna Svenska Electriska Aktiebolaget)

THE Swedish power reactor development programme has largely been concentrated on the natural uranium-heavy water system, but so far no heavy water has been produced in Sweden. Since 1954, however, the possibilities for the production of heavy water have been investigated by ASEA, as a complement to its activities in the nuclear energy field, and for the past two years this development programme has been continued in close co-operation with, and financed by, the semi-State company AB Atomenergi.

Estimated Heavy Water Requirements

Swedish power consumption is increasing at a rate of about 6% a year and during the 1970s an increasing amount of nuclear power will probably be needed in addition to the hydro-electric power now constituting the corner-stone of Swedish power production. It has been estimated that during a 10-year period, starting sometime during the '70s, about 500 MWe of nuclear power should be added each year.

The amount of heavy water required per installed MWe will depend on the reactor type chosen but 0.8 tonne/MWe is regarded as a realistic figure. Other types of reactor may enter the picture, but assuming that all stations will be of the heavy water type, about 400 tonnes of heavy water a year would thus be needed for new installations during this 10-year period and additional quantities would be required for covering losses from operating reactors.

Even if this figure is a rather rough approximation, it indicates quite clearly that there are good reasons for investigating the possibilities of supplying the heavy water required for the Swedish reactors by domestic production.

The ASEA D_2O Development Programme

In 1954 when ASEA started its heavy water production studies little was known about the American activities in this field and the world market was dominated by the Norwegian company, Norsk Hydro, selling about 10 tons a year at about £30/lb.

The possibilities of producing heavy water as a by-product of the Swedish ammonia plants by electrolysis or low temperature distillation of hydrogen were discussed but were considered technically uninteresting because only a few tons a year could be produced in this way.

Attention had been brought to some notes from Germany about a method involving isotope exchange between hydrogen sulphide and water. Little was known about the technical possibilities of this process and a lot of problems could be anticipated because it involved large volumes of hydrogen sulphide under high pressure. Still, it looked attractive, one advantage being that the process could be employed independently of other chemical industries, thus not being subject to any capacity limitations.

The ASEA programme was concentrated entirely on this process and during 1955 and 1956 a small pilot plant was erected and operated and at the same time preliminary, technical and economic process studies were made. In the autumn of 1955 the U.S. AEC entered the heavy water market, reducing the world market price to about one-third of that previously obtaining, but in spite of this fall the ASEA programme was continued.

In early 1959 a larger pilot plant (Fig. 1) was put into operation and a little later heavy water became available from the AEC plants. Information from the pilot plant and the AEC is now forming a valuable background for the plant design studies in progress.

The Swedish heavy water production studies should be looked upon as part of a long-term programme. The U.S. AEC is selling heavy water at cost price—£10/lb—from installations with great excess capacity so there is no urgent need for a domestic production.

If, however, the heavy water power reactor design studies now in progress in Sweden make future advances along this line probable, it could be advantageous with a moderate scale heavy water production to gain practical experience for later and much larger plants

The Hydrogen Sulphide Process

Hydrogen sulphide and water in contact with each other exchange hydrogen atoms and, owing to the dissociation of both substances, this isotope exchange will proceed very rapidly without any catalysts being needed. The bond between deuterium and oxygen is stronger than between

deuterium and sulphur, however, the result being that at equilibrium the deuterium content of the water will be greater than that of the hydrogen sulphide.

The equilibrium constant for the distribution of deuterium between water and hydrogen sulphide is temperature dependent. If the temperature of an H_2S/H_2O system in equilibrium is increased, deuterium will be transferred from the water to the gas and this is technically utilized for heavy water enrichment in a system consisting of a cold tower and a hot one as appears in Fig. 2.

Feed water is introduced at the top of the cold tower, passed once through the system while hydrogen sulphide gas is constantly circulating counter-currently to the water.

If the cold tower is kept at, for instance, 30°C and the hot one at 130°C, and if the molar flow ratio H_2S/H_2O is carefully controlled, the deuterium transport capacity of the water will be greater than that of the gas in the cold tower and smaller than the gas transport capacity in the hot one. In other words, the absorption factor for deuterium will be greater than unity in the cold tower and smaller than unity in the hot one.

As a result of this, part of the deuterium being transferred by the water from the cold tower to the hot one will be put back to the cold tower by the gas, and there will be a higher deuterium concentration in the water at the bottom of the cold tower than in the feed water. From the bottom of the cold tower enriched water can be withdrawn and used as feed for a subsequent unit where it may be further enriched in the same or in other ways.

An operating pressure between 300 and 350 p.s.i., a cold tower temperature between 30° and 35°C, and hot tower temperature between 120° and 140°C have been found to represent technically suitable process conditions. The high pressure is essential to keep down the steam content of the hot tower gas, and thereby the process heat requirements.

Hydrogen sulphide is a corrosive, inflammable and extremely poisonous gas which makes a proper process design dependent upon the solution of a great number of technical problems, often connected with safety matters.

Design Study for a 40 tonne/Year D_2O Plant

The design capacity of the plant study to be presented here is 40 tonnes of heavy water per 8,000 hours.

The plant has been designed to operate as a separate production unit with its own workshop, office, laboratory, etc., but because of special conditions for this project the steam is assumed to be bought from an outside source, and thus no steam generating plant has been incorporated.

The primary enrichment up to about 12% D_2O is performed in two parallel identical two-stage units operating independently of each other. The product from the two primary plant units goes to a secondary plant where it is concentrated to about 50% D_2O in a hydrogen sulphide unit and finally concentrated to 99.7% D_2O by vacuum water distillation.

A simplified flow diagram for one primary plant unit appears in Fig. 3. A layout study for one such unit is shown in Fig. 4 and some general data has been compiled in Table 1.

TABLE 1

Primary plant unit data:	
Production (as 100% D_2O)	20 t/8,000 h
Operating pressure	320 p.s.i.
Tower temperatures	32 and 130°C
Recovery	17%
Steam consumption	13 t/h
Electricity consumption	1,600 kW
Feed water flow rate	88 t/h
Time to reach equilibrium	12 days
Product concentration from stage I	0.21% D_2O
Product concentration from stage II	12% D_2O
Tower type	perforated plates
Tower diameter: stage I, cold tower	12 ft 6 in.
stage I, hot tower	12 ft 6 in.
stage II, cold tower	3 ft 8 in.
stage II, hot tower	3 ft 8 in.
Tower height	165 ft

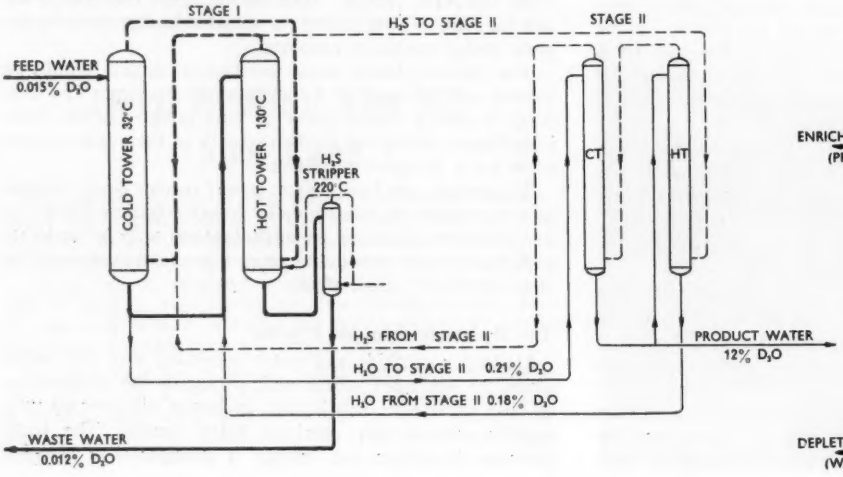
Most of the process equipment will be made in stainless steel of the 18/8 type with Mo. A mild steel alternative has been studied but its lower initial cost has not been found to compensate for the increased operating difficulties and maintenance problems connected with the hydrogen sulphide corrosion on mild steel.

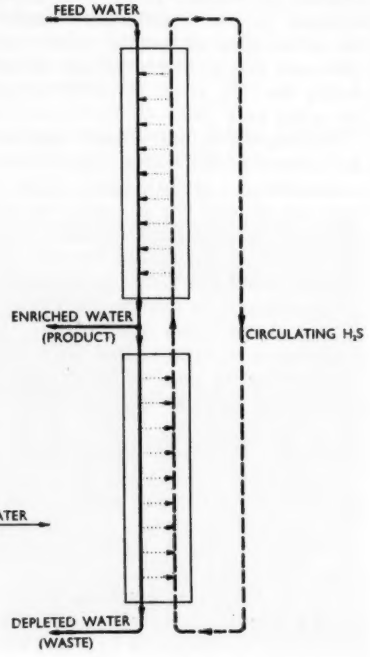
Either high grade stainless steel or mild steel should be used for this process while intermediate materials should be avoided because generally they are sensitive to hydrogen sulphide stress corrosion cracking which may cause very serious safety problems in connection with a process like this where large volumes of hydrogen sulphide are kept under high pressure. The towers will be of stainless clad mild steel.

An efficient heat recovery system will be of prime importance to any plant, but the optimum heat recovery will be dependent not only on the steam price but also on

Fig. 2.—(Right) The hydrogen sulphide process principle.

Fig. 3.—(Below) Simplified flow diagram for two stage primary plant unit.





write-off time and interest, because the steam cost must be balanced against capital cost for heat recovery equipment.

The plant outlined above has been designed for a very good heat recovery with correspondingly high heat exchanger costs. Another design more suitable for a shorter write-off time has been studied, where heat exchanger costs for each primary plant unit have been reduced by £170,000 with a corresponding increase in steam consumption from 13 to about 18 tons an hour.

It has not been possible to calculate any optimum primary plant unit size but it seems to correspond to a capacity between 15 and 30 tons of heavy water a year, primarily because investment costs for a primary plant unit are dominated by tower and heat exchanger costs, both of which will be practically proportionate to unit capacity, even at this moderate unit size. In addition to technical arguments against too-large units, it is a marked advantage from the plant safety point of view to avoid unnecessarily large hydrogen sulphide containing towers.

Cost Estimation

Costs have been estimated for a complete "grass roots plant" but without steam generating facilities. So far no site has been chosen for the plant and therefore only rough cost figures for supplying water to the plant and for external roads have been included in the estimate.

Estimated investment cost is intended to include all costs until the plant is in real production, and besides general contingency, design and purchase costs, interest during construction and start-up costs have been included. Start-up costs consist partly of salaries and wages for the operating crew during a training period before first start-up and partly of total operating costs for a period of four months, which is roughly estimated to compensate for the reduced production during the first year of plant operation.

TABLE 2

	£/unit	£
Investment cost:		
Primary plant:		
Towers	319,000	
Heat exchangers	252,000	
Pumps	8,000	
Blowers	17,000	
Piping system	121,000	
Instrumentation	39,000	
Found. and struct. steel	48,000	
Miscellaneous	7,000	
	811,000	1,622,000
	£	£
Primary plant auxiliary:		
H_2S synthesis and storage	82,000	
H_2S purification	10,000	
Storage tanks	13,000	
Flare stack	12,000	
	117,000	117,000
Secondary plant		142,000
Auxiliaries and miscellaneous		653,000
Water treatment and distribution, electrical, workshops, spare parts inventory, buildings, interconnecting piping, site, site preparation, etc.		
		2,534,000
Contingency 10%		253,000
Design and purchase		35,000
Interest during construction		173,000
Start-up costs		207,000
Total investment cost		3,302,000
	£/year	%
Operating cost:		
Salaries and wages including overheads	83,000	23
Administration	7,000	2
Steam (28 t/h, 11 s/t)	130,000	34
El. power (3,270 kW, £28/kWy)	90,000	23
Water (3.6 Mm^3/y)	12,000	3
Maintenance (materials only)	28,000	7
Miscellaneous	12,000	3
	362,000	
Contingency 5%	18,000	5
Total operating cost	380,000	100

The design and purchase cost figure is rather low because most of the design cost will go into the present development budget.

Total Manufacturing Cost

From the above tables total manufacturing cost has been calculated for various amortization rates assuming 6% interest.

TABLE 3

Write-off time (years)	Total manufacturing cost	
	£/year	£/lb D_2O
6	1,020,000	11.5
8	880,000	10.0
10	800,000	9.1
12	750,000	8.5
14	710,000	8.1
16	680,000	7.8

Cost Conditions for Bigger Plants

Based on the design studies and cost estimates for this 40 t/year plant, investment and operating costs for bigger plants have been calculated. A summary of the results is

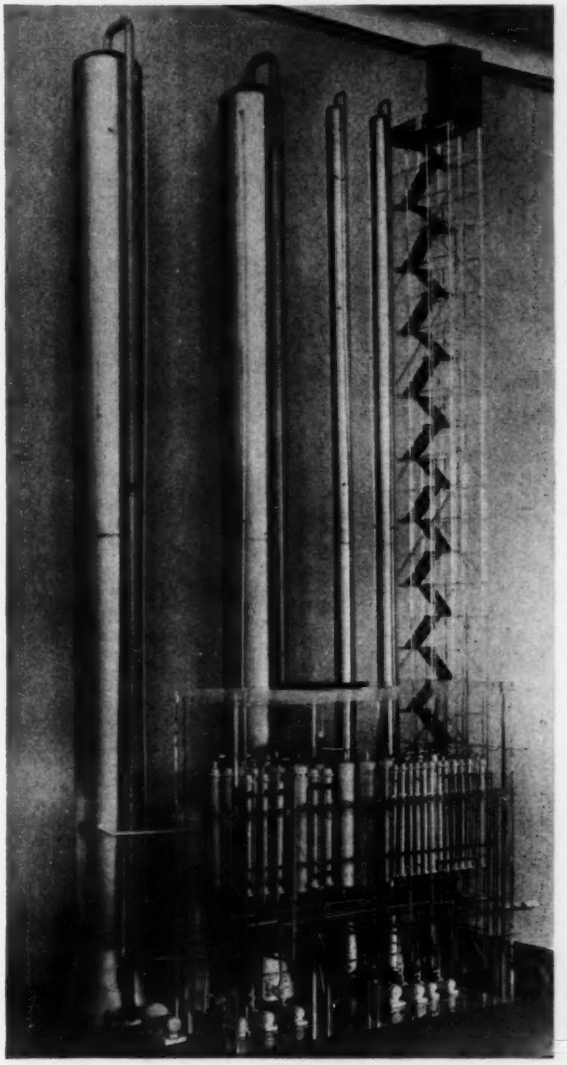


Fig. 4.—Process lay-out model study for primary plant unit.

given in Table 4, which is based on 10 years write-off and 6% interest.

TABLE 4

Production t/year	Investment cost M£	Manufacturing cost £/lb D_2O
40	3.2	11.5
60	4.4	10.8
80	5.5	10.4
100	6.9	10.2
200	12.6	9.8

Cost Comparison

A rather well-defined relationship, varying for different kinds of chemical industries, has been found to exist between the ratio of invested capital to production sales value per year, that is the so-called capital ratio, provided there is a free and stable market, meaning normal competition and not too short write-off time.

This capital ratio has been studied for the American chemical industry, but for its heavier part where the high American wage level is of less importance the result should be valid at least to some extent even for European conditions.

In order to get an idea about the cost situation for heavy water manufacture by the hydrogen sulphide process as compared with the chemical industry in general, a capital ratio figure based on this Swedish cost estimation may be compared with capital ratio figures for the American chemical industry as given in literature.

The capital ratio has been found to increase slightly year after year but for 1958 the following figures have been given:—

	Capital Ratio
Petroleum	3.08
Heavy inorganics	2.24
Pulp and paper	2.01
Rubber	1.04
Pharmaceuticals	0.42

The table, which has been compiled from a bigger one, illustrates the fact that the highest capital ratio will be found in large volume technologically complex industries.

Based on the estimated investment cost for the Swedish 40 t/year plant and the present AEC price the capital ratio will be 3.6, which is considerably higher than for other comparable chemical industries.

Technically as well as economically there will be a certain similarity between a heavy water plant utilizing the hydrogen sulphide method and the process units of the petroleum industry. Applying the capital ratio of the petroleum industry to the 40 t/year heavy water plant a sales price of about £12/lb is found, but for a 100 t/year plant a sales price very close to the present American one, that is £10/lb, will be obtained.

Arriving at almost exactly the present heavy water price by calculating a "reasonable future sales price" in such a strange way should of course be considered a pure accident, but nevertheless it may perhaps to some extent indicate that even on a much bigger future heavy water market the heavy water price will not be very different from the present one.

NEW BOOKS

Principles of Radiation Dosimetry, by G. N. Whyte (124 pp., 44 illus. (John Wiley and Sons, New York), Chapman and Hall, Ltd., 56s.)

This book is intended, primarily, for the science graduate faced with the problem of determining radiation dose. As the author himself points out, in his preface, difficulties in radiation dosimetry have been caused quite as often by lack of understanding of the qualities being measured as by inadequacies in equipment or technique. The relationship between basic parameters of the radiation field, such as intensity and spectral distribution, are not always firmly grasped, and particular emphasis is placed right at the beginning of the book on the nature of the radiation field, and the interaction of radiation with matter. Further chapters cover the determination of X-ray spectral distribution; the measurement of exposure dose; the measurement of absorbed dose for X-rays; dosimetry of charged particles; dosimetry of neutrons. The principles of instruments are dealt with in the final chapter. The author is Associate Professor of Physics at Queen's University (Canada), and has also served as Research Officer with the X-rays and Nuclear Radiation Section of the National Research Council at Ottawa. and is also a member of Committee III of the International Commission of Radiological Units and Measurements. It is, therefore, natural that when using concrete problems to illustrate principles, he should incline to biological and medical aspects, and to X-rays, whereas readers in the nuclear engineering field would prefer rather more emphasis on γ-radiation from isotopes, such as fission products. This, however, does not alter the fact that the author has given us a very clear and logical explanation of the basic principles of the subject.

Progress in Nuclear Energy—Law and Administration. Edited by Herbert S. Marks. (994 pp., Pergamon Press, £9 9s.)

Here at last is a complete survey of the law and administration relating to nuclear energy, both international and national. Volume I of this scholarly book contains eleven general articles on law and administration in various lands, including an excellent and comprehensive chapter on the United Kingdom by L. J. Blom-Cooper. The second volume sets out legislation and administrative procedures and practices relating to all aspects of nuclear energy, in 25 different countries. The book concludes with the treaty establishing Euratom, particulars of OEEC, some typical bilateral agreements and the statute of the International Atomic Energy Agency.

There are few lawyers with a grasp of this field, and in this invaluable volume many of them have helped to compile a comprehensive reference book, which is well and authoritatively written, neatly and logically presented and, in every way, justifies the high price which the publishers have placed on it.

Are you considering trying to export to Japan or Turkey, the Phillipines, Sweden or the U.S.A.? Then here you will find the laws and arrangements which you will run into on the other side. And what about the English statutes and arrangements—do you really understand these? If not, the chapter by Mr. Blom-Cooper will do more in its 33 pages to put you right than any other source we know, even of ten times the length. And what about that agreement between the U.S.A. and the U.K. about tube alloys . . . wasn't there an exchange of notes between the U.K. and Norway about the peaceful uses of atomic energy in 1957. . . . And what exactly was it that the Fleck Committee recommended? Here are your answers, your references, your carefully sub-divided bibliography.

This book is intended to provide "A valuable reference work and source of information for all concerned with or interested in . . . the legal and administrative aspects of nuclear energy." It fulfils its function with unusual success. G.E.J.

Effects of Nuclear Radiation on Men and Materials. By Dr. T. C. Helvey. (56 pp., 23 illus. (John F. Rider, New York), Chapman and Hall, Ltd., 15s.)

Written practically entirely from the standpoint of those interested in nuclear propulsion of aircraft and other vehicles, this book is, nevertheless, a readable introduction to the subject, which is dealt with under four headings, commencing with the basic concepts of radiation and nuclear particles, and their behaviour. The effects of radiation on men are considered, and tolerances and symptoms, both immediate and genetic, are explained. Effects on the physical properties of materials are considered while, in conclusion, some attention is given to shield configuration.

The book does not in any way claim to be a textbook on the subject—its size alone would preclude it—and its chief appeal is to those who, whatever their other qualifications, are laymen in the radiation field. J.A.B.-B.

Simulating Power Reactors

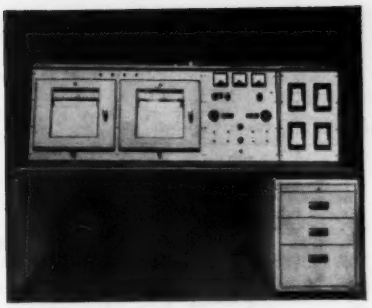


Fig. 1.—General Precision Systems' analogue power reactor simulator.

The training value of a simulator may be impaired if two separate power scales are used with a consequent discontinuity in changing from one to the other. In a recent design for AERE, Harwell, the analogue computation of the power kinetics is undertaken on a logarithmic basis.

By D. P. MARKHAM
(Head of Industrial Control Division, General Precision Systems, Ltd.)

THE use of analogue computers to simulate physical phenomena has been one of the most useful aids to development in the scientific and engineering world, but the requirements or specification of such a computer vary quite considerably according to the application involved. As a means for scientific investigation of certain properties of a system it may be that fast response times are required or high accuracies over a limited range of the parameters are a necessity, and in such applications a true mathematical analogue of the physical system is employed whenever possible.

Where such an equipment is required for training purposes and not for scientific investigation, then a different kind of problem presents itself. The machine must behave exactly like its antitype and must be able to cover the full range of parameters encountered in practice, otherwise the full value of the machine as a training aid is lost. This last faculty has proved particularly difficult in the simulation of a power reactor, for in no other physical phenomena does the main parameter (power or neutron density) vary over such a wide range.

Most power reactor simulators have had to operate over two different power ranges with a discontinuity between them; this has limited the training value of such a simulator. In reality the actual power output of any reactor, whether operating or shut down, must always be indicated to the operator, and this means that anything up to 10 decades of power level must be accommodated. This is impossible with normal simulation techniques as, before this range is covered, trouble with noise level and signal drift is experienced.

To overcome this problem, General Precision Systems, Ltd., have recently designed a reactor simulator for AERE, Harwell, in which the analogue computation of the power kinetics has been undertaken on a logarithmic basis*. This approach has resulted in the successful coverage of 10 decades of power operation with the normal 0–100V d.c. analogue computing components.

If we consider the kinetic equations of a nuclear reactor, the rate of change of neutrons with time is given by the equations:

$$\frac{dn}{dt} = (\varrho - c)\frac{kn}{\tau_o} + \Sigma\frac{r_j}{\tau_j} + S \qquad (1)$$

and

$$\frac{dr_j}{dt} = kc\mu_j\frac{n}{\tau_o} - \frac{r_j}{\tau_j}. \qquad (2)$$

Where : n = number of neutrons in the reactor system at time t.
k = infinite reproduction constant.
c = delayed neutron fraction.
τ_o = mean lifetime of neutrons in an infinite system.
r_j = number of delayed neutron emitters of type j.
S = source strength.
μ_i = relative yield of r_j in fission.
τ_j = mean lifetime of r_j.
ϱ = reactivity = $(k_e - 1)/k_e$.

* Patent applied for.

If the power is defined as:

$$P = kn/\tau_o$$

and also define

$$\tau' = \tau_o/k$$

then we have the equations for the power as:

$$\tau'\frac{dP}{dt} = (\varrho - c)P + \Sigma\frac{r_j}{\tau_j} + S \qquad (3)$$

and

$$\frac{dr_j}{dt} = c\mu_j P - \frac{r_j}{\tau_j}. \qquad (4)$$

In order to transpose the variable P into the form $\log P$, divide equations (3) and (4) by P. Then

$$\tau'\frac{d(\log P)}{dt} = (\varrho - c) + \Sigma\frac{r_j}{\tau_j P} + \frac{S}{P} \qquad (5)$$

$$\frac{1}{P}\frac{dr_j}{dt} = c\mu_j - \frac{r_j}{P\tau_j}. \qquad (6)$$

Now we can conveniently define new variables given by:

$$x_j = r_j/P$$

from which we obtain the final equations:

$$\frac{d(\log P)}{dt} = \varrho - c + \Sigma\frac{x_j}{\tau_j} + \frac{S}{P} \qquad (7)$$

$$\frac{dx_j}{dt} + x_j\frac{d(\log P)}{dt} + \frac{x_j}{\tau_j} = c\mu_j. \qquad (8)$$

These equations present the dynamics of the reactors in terms of $\log P$, with the exception of the Source item which is only significant at low powers as this item involves the reciprocal of Power. In the simulator the power range was 0.1 W to 10^9 W, which when scaled over the standard analogue voltage range of 0–100, conveniently gave a 10 volts change as equivalent to one decade in power level.

With the exception of the " log power " recorder, most of the display equipment is operated from linear signals. Therefore the problem of supplying the appropriate signals should now be considered.

The main instruments required for regulating a reactor are:

(i) Power deviation meter.
(ii) Doubling time indicator.
(iii) Rod position indicators.
(iv) Linear power recorder.

Power Deviation

For computing the power deviation, a voltage equivalent to P_d is applied to the system.

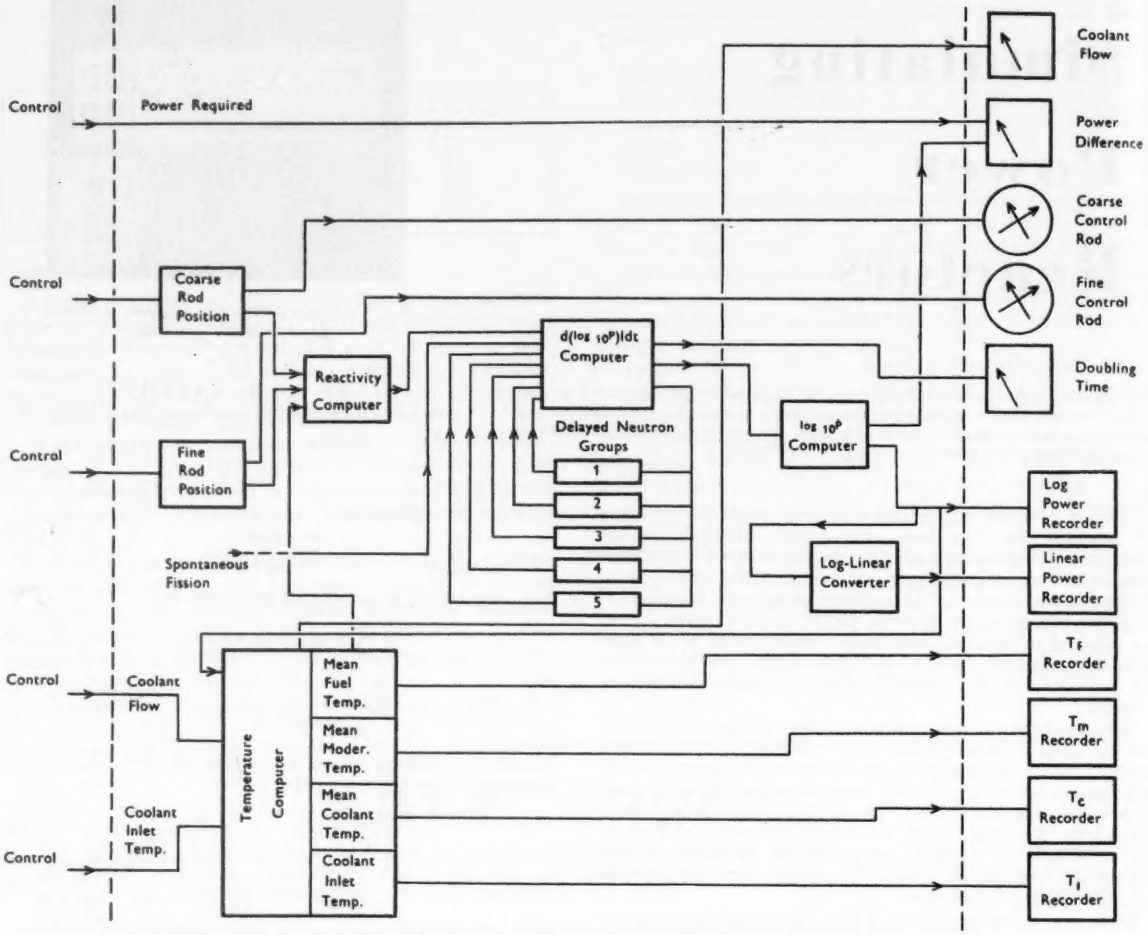


Fig. 2.—Block diagram of the logarithmic reactor simulator which is based upon the theoretical analysis outlined.

The difference voltage

$$V' = k \log \frac{P}{P_d} = k \log \left(1 + \frac{\Delta}{P_d}\right)$$

where $$\Delta = P - P_d.$$

Expanding this expression:

$$V' = \frac{\Delta}{P_d}\left[1 - \tfrac{1}{2}\left(\frac{\Delta}{P_d}\right) + \tfrac{1}{3}\left(\frac{\Delta}{P_d}\right)^2 \cdots\right]$$

and as a first approximation:

$$V' \fallingdotseq \frac{\Delta}{P_d} \quad \text{or} \quad \Delta \fallingdotseq P_d V'.$$

The error of approximation increases at low power levels, but as the meter is a null device and the error diminishes as $\Delta \to 0$, this is satisfactory.

Doubling Time

If the reactor is considered as operating at some power P_o, and the reactivity is increased by a small amount, examination of the kinetic equations shows that the increase of P is very nearly exponential in the form $P = P_o e^{\lambda t}$, where λ is a constant for a given step in reactivity.

Therefore $$\frac{P}{P_o} = e^{\lambda t}$$

and $$\log \frac{P}{P_o} = \lambda t$$

also $$d\frac{\log P}{d_t} = \lambda.$$

Now the power doubles in a time given by:

$$\frac{2P_o}{P_o} = e^{\lambda td}$$

or $$td = \frac{\log_e 2}{\lambda}$$

where td = doubling time.

$$\therefore \quad td = \frac{\log_e 2}{d(\log P)/dt}$$

and the value of $\dfrac{d(\log P)}{dt}$ is readily available.

Rod Position Indicator

The rod position is a linear function of reactivity, and as this only appears in the kinetics in a linear form, it presents no difficulty.

Linear Power Record

Here a straight log to linear conversion must be undertaken, but with the aid of non-linear networks the total range can be covered with suitable accuracy.

A typical block diagram of a Reactor Simulator of the type described appears above (Fig. 2) and the Control Console is shown in Fig. 1, on the preceding page.

TRANSLATIONS

A Résumé of Principal Articles

Analyse de Fausses Fermetures .. (383)

Analyse des Pannes des Réacteurs de Recherches .. .. (385)

Vers une plus grande sûreté de fonctionnement .. .. .. (391)

La publication d'un article précédent (Juin 1960, page 241) sur la question précédente a stimulé la discussion parmi les ingénieurs en instrumentation et les opérateurs de réacteurs dans le monde entier. Dans ce numéro nous revenons sur cette analyse importante, tout d'abord en reproduisant notre questionnaire original de sorte que les lecteurs puissant apprécier eux-mêmes les questions sur lesquelles se basait notre analyse.

Cela est suivi par des commentaires pleins d'à-propos sur le choix d'instruments par deux membres du personnel du Central Electricity Generating Board dont les opinions sont exprimées sur une base purement personnelle.

La Surchauffe et le Réacteur à Eau Bouillante. 1. Pourquoi et Comment. (393)

La surchauffe nucléaire aujourd'hui et demain .. .. (395)

Le Projet " Pathfinder " du CRBR .. (397)

Le premier article de cette série est une étude préliminaire du parti qu'on peut tirer de la vapeur de meilleure qualité que la vapeur saturée obtenue normalement des réacteurs à eau bouillante. On y fait mention de l'emploi de la surchauffe fossile qui, bien qu'elle ne conribue rien à la technologie nucléaire, peut entraîner des économies considérables de dépenses de capitaux et de fonctionnement.

Le second article fait ressortir le besoin de la surchauffe et évalue la valeur capital de réductions de taux de chauffe deturbines même les plus petits. Il passe en revue la domaine de la surchauffage nucléaire des points de vue actuel et futur, et donne une brève description d'un projet futur d'une installation d'un rendement de 330 MWe, avec surchauffe intégrale et un réchauffeur nucléaire séparé.

Dans le troisième article, on trouvera une coupe d'un réacteur eau bouillante à recirculation réglée " Pathfinder " d'Allis-Chalmers, d'un rendement de 66 MWe, actuellement en construction à Sioux Falls, South Dakota.

Réacteurs d'Energie petits et moyens (400)

Conférence sur la Dosimétrie des Radiations .. .. (401)

Convention de Responsabilité Civile .. (403)

La Soudure de L'Aluminium et la Manipulation .. .. .. (405)

Production d'Eau Lourde en Suède .. (409)

Les méthodes suédoises de soudure de l'alumium sont passées en revue dans cet article écrit par un ingénieur membre d'une des plus grandes entreprises d'aluminium de la Scandinavie. Cette société a récemment terminé des travaux considérables de soudure d'aluminium et de manipulation au centre de réacteur de Studvik au Sud de la Suède, et a exécuté des travaux sur aluminium pour des centres nucléaires aux Pays-Bas et en Belgique.

Die Analyse von falschen Stillsetzungen .. .. (383)

Fehler-Analyse in Forschungs-Reaktoren .. .. (385)

Auf dem Weg zu grösserer Verlässlichkeit .. .. (391)

Die Veröffentlichung eines früheren Aufsatzes (Juni 1960, Seite 241) über das obige Thema hat eine Diskussion unter Instrument-Ingenieuren und Reaktor-Betriebsleuten in der ganzen Welt angeregt. Wir kommen in diesem Heft auf die wichtige Analyse zurück, zunächst, indem wir unseren ursprünglichen Fragebogen reproduzieren, sodass die Leser selbst sehen können, auf welchen Fragen unsere Analyse basiert war.

Es folgen dann einige sachliche Bemerkungen hinsichtlich der Wahl der Instrumente von zwei Angestellten des Central Electricity Generating Board, deren Ansichten aber durchaus persönlich zu verstehen sind.

Ueberhitzung und der B.W.R.1. Warum und Wie .. .. (393)

Ueberhitzung in der Atomtechnik zur Zeit und in der Zukunft .. .. (395)

Projekt "Pfadfinder" CRBR .. .. (397)

Der erste Aufsatz in dieser Serie ist eine einführende Studie über die Vorteile, die man mit Dampf höherer Qualität erreicht, gegenüber gesättigtem Dampf, wie er gewöhnlich von Siedewasser-Reaktoren geliefert wird. Die Anwendung von Ueberhitzung durch fossile Brennstoffe wird erwähnt, die, wenn sie auch nicht zur Atom-Technologie beiträgt, zu beträchtlichen Ersparnissen sowohl in den Kapitals-, als auch in den Betriebskosten führen kann.

Der zweite Aufsatz betont die Notwendigkeit Ueberhitzung anzuwenden und bringt eine Schätzung des Kapitalswertes von schon kleinen Verringerungen der Turbinen-Wärmezahlen. Es folgt eine Uebersicht über das Feld der Ueberhitzung in der Atomtechnik vom gegenwärtigen Standpunkt aus und wie es in Zukunft sein wird, und es wird dann eine kurze Beschreibung gebracht von einem zukünftigen Projekt einer Anlage für eine Leistung von 330 MWe mit eingebauter Ueberhitzung und einem gesonderten Atomkraft-Wiedererhitzer.

Kleine und mittlere Leistungs-Reaktoren .. .. (400)

Die Konferenz uber Messung von Strahlungsmengen .. .. .. (401)

Vereinbarung über die Haftpflicht gegenüber einem Dritten .. .. (403)

Die Schweissung und Handhabung von Aluminium .. .. .. (405)

Die Produktion von schwerem Wasser in Schweden .. .. (409)

In diesem Aufsatz, der von einem Ingenieur eines der grössten Aluminium-Konzerne in Skandinavien geschrieben ist, werden die schwedischen Verfahren zum Schweissen von Aluminium besprochen. Die Gesellschaft hat kürzlich umfassende Schweiss- und Handhabungs-Arbeiten mit Aluminium im Reaktor-Zentrum Studsvik in Süd-Schweden zu Ende gebracht und hat ferner Arbeiten mit Aluminium für Atom-Zentren in den Niederlanden und in Belgien durchgeführt.

Análisis de Paradas Espurias .. .. (383)

Análisis de Fallas en Reactores de Investigación .. .. (385)

Hacia una Mayor Seguridad .. .. (391)

La publicación de un artículo anterior (Junio de 1960, página 241) sobre este asunto ha estimulado la discusión entre los ingenieros de instrumentación y los operadores de reactores en todas partes del mundo. En este número, volvemos a este importante análisis, primeramente con la reproducción de nuestro cuestionario original, de modo que nuestros lectores pueden apreciar ellos mismos las preguntas sobre las que nuestro análisis fué basado.

Esto va seguido de algunos comentarios pertinentes sobre la selección de instrumentos contribuídos por dos miembros del personal del " Central Electricity Generating Board " (C.E.G.B.), cuyos puntos de vista son expresados en una capacidad enteramente personal.

Supercalor y el Reactor de Agua Hirviente. 1. ¿ Por qué y Cómo .. (393)

Supercalor Nuclear Hoy y Mañana .. (395)

Proyecto CRBR " Pathfinder " .. (397)

El primer artículo de esta serie es un estudio preliminar de los beneficios obtenibles con vapor de más elevada calidad que el vapor saturado normalmente obtenido de los reactores de agua hirviente. Se hace mención del uso de " supercalor fósil " el que, aunque nada contribuye a la tecnología nuclear, puede resultar en economías considerables tanto en capital como en los gastos de operación.

El segundo artículo hace hincapié en la necesidad de supercalor y calcula el valor capital aun de pequeñas reducciones en las razones de calor turbínico. Pasa en revista el campo de supercalentado nuclear desde los puntos de vista de la actualidad y del porvenir, y da una breve descripción de un futuro proyecto para una planta de 330 MWe de rendimiento, con supercalor integral y un recalentador nuclear separado.

En la tercera sección, se ofrece una sección del reactor de agua hirviente y de recirculación controlada Allis-Chalmers " Pathfinder," con rendimiento de 66 MWe que está actualmente en construcción en Sioux Falls, South Dakota.

Reactores de Energía Pequeños y Medianos .. .. (400)

Conferencia sobre Dosimetría de Radiación .. .. (401)

Convención de Responsabilidad Civil.. (403)

Soldadura de Aluminio y Manipulacion (405)

Producción de Agua Pesada en Suecia (409)

Los métodos suecos de soldadura de aluminio se discuten en este artículo escrito por un ingeniero de una de las más grandes empresas de la industria de aluminio en Escandinavia. Dicha Compañía recientemente ha completado una extensa obra de soldadura de aluminio y trabajo de manipulación en el centro reactor de Studevik en Suecia Meridional y ha llevado a cabo obras relacionadas con aluminio para otros centros nucleares en los Países Bajos y en Bélgica.

Personal

Dr. F. A. Vick

Dr. R. Spence

Mr. L. Grainger

Mr. R. Foxwell

Appointments

Dr. F. A. Vick, formerly deputy director, as director of Harwell; **Dr. R. Spence,** formerly chief chemist, as deputy director and **Mr. L. Grainger,** formerly head of metallurgy, as assistant director. **Sir Basil Schonland** continues as director of the Research Group until his retirement early next year.

Mr. R. Foxwell to the SIMA council.

Mr. D. Handley as technical director and **Mr. M. T. Cunningham** as chief engineer of Dewrance.

Sir Charles Goodeve has been nominated as president-elect of the Iron and Steel Institute.

Mr. G. N. Green as chairman of the North Eastern Electricity Board. **Mr. J. D. Nicholson** becomes deputy chairman.

Mr. G. E. Smith as assistant managing director of Hamworthy Engineers.

Mr. B. G. S. Donald to the board of Metal Agencies.

Mr. D. L. Campbell and **Mr. W. C. Bell** to the board of Wellman Smith Owen Engineering.

Mr. H. A. A. White as general export manager of the United Steel Companies.

Mr. A. B. Coussmaker as chairman of Johnson Matthey.

Mr. R. J. Assheton to the board of Borax Consolidated.

G.E.C. appointments following a branch representation reorganization are: **Mr. E. W. Molesworth,** London Eastern and Southern England; **Mr. J. R. Mercer,** Scotland; **Mr. V. F. Ellison,** Yorkshire and the North East; **Mr. O. S. Chalmers,** North Western and North Wales; **Mr. W. R. Greves,** Midlands and South Wales.

Mr. W. J. Fry as sales director and commercial manager of Solartron-John Brown Automation.

Mr. E. B. Thain as manager of Yates Plant.

Mr. F. Baillie as production manager of Cambridge Instruments, and **Mr. P. Goudime** to the board.

Mr. D. A. F. Donald as chairman of G. A. Harvey.

Mr. L. M. Broadway as chairman of Metal Cleaning, **Mr. J. A. V. Watson** becomes deputy chairman.

Mr. L. A. Armstrong as chief designer of K.D.G. Instruments.

Mr. R. Broughton as chief of technical sales of Pulsometer Engineering.

Mr. P. A. R. Wright as sales manager of the Burgess Hill office of Short Brothers and Harland.

Mr. R. Hussey to the board of James Gordon.

Sir Hamish D. MacLaren as president: **Mr. C. T. Melling** and **Mr. B. Donkin** as vice-presidents; **Mr. C. E. Strong** as honorary treasurer have been nominated by the Institution of Electrical Engineers.

Mr. G. Sims-Davies as general manager of Hancock (Engineers).

Mr. K. E. Merefield and **Mr. W. B. Sallitt** to the board of Superheater.

Mr. A. Hayes as chief sales engineer for mining products; **Mr. W. T. Jones** as new manager of the mining division; **Mr. R. Marshall** as technical represenative for Scotland; **Mr. R. Noren** as manager for stationary compressor sales of Atlas Copco.

Mr. A. Signorini as general manager of Pirelli-General Cable.

Mr. L. A. Lloyd as spares and service manager of Thos. W. Ward's contractors' plant department.

Mr. D. F. Haydon as general sales manager of Baird and Tatlock.

Mr. D. P. C. Neave as vice-chairman of Wolverhampton Metal.

Mr. H. M. Henderson to the board and general manager of Workington Iron and Steel.

Mr. K. N. Swash and **Mr. M. A. Slater** to the board of Contactor Switchgear.

Mr. T. Ingledow to the board of Balfour Beatty (Overseas).

Mr. F. Baillie

Mr. W. Fry

Sir Leslie Gamage

Mr. H. G. Davey

Overseas

Mr. R. W. Griffiths as the director of western marketing of Vitro, and **Dr. S. Grand** as head of the chemistry and arc research department.

Mr. J. D. Bond as a hearing examiner at the AEC's Federal Communications Commission, and **Mr. G. Sipkin** as a member of the patent compensation board.

Mr. Y. Keynan as the Israel Minister to the IAEA.

Dr. G. Murphy as head of the newly formed department of nuclear engineering at Iowa State University.

Mr. A. L. Kohl as assistant group leader in organic reactors of Atomics International.

Mr. G. A. Saar as general manager, mechanical departments, and **Mr. W. M. Terry** as general manager, electrical department of Allis-Chalmers Industrial Equipment Division.

Mr. W. K. Whiteford to the board of International Nickel.

Awards

Dr. W. Deuchars of the U.K. AEA a scholarship for scientific research by the Australian Academy of Sciences.

Resignations

Mr. E. B. Rees as export manager of the United Steel Companies.

Sir Willis Jackson as director of research of AEL to become Professor of Electrical Engineering at Imperial College.

Sir Thomas Overy as chairman of G. A. Harvey.

Retirements

Sir Leslie Gamage as chairman and managing director of General Electric.

Mr. W. W. Hackett as chairman of Accles and Pollock.

Mr. R. H. McCulloh as manager of the U.S. AEC's Portsmouth area.

Mr. G. C. H. Matthey as chairman of Johnson Matthey.

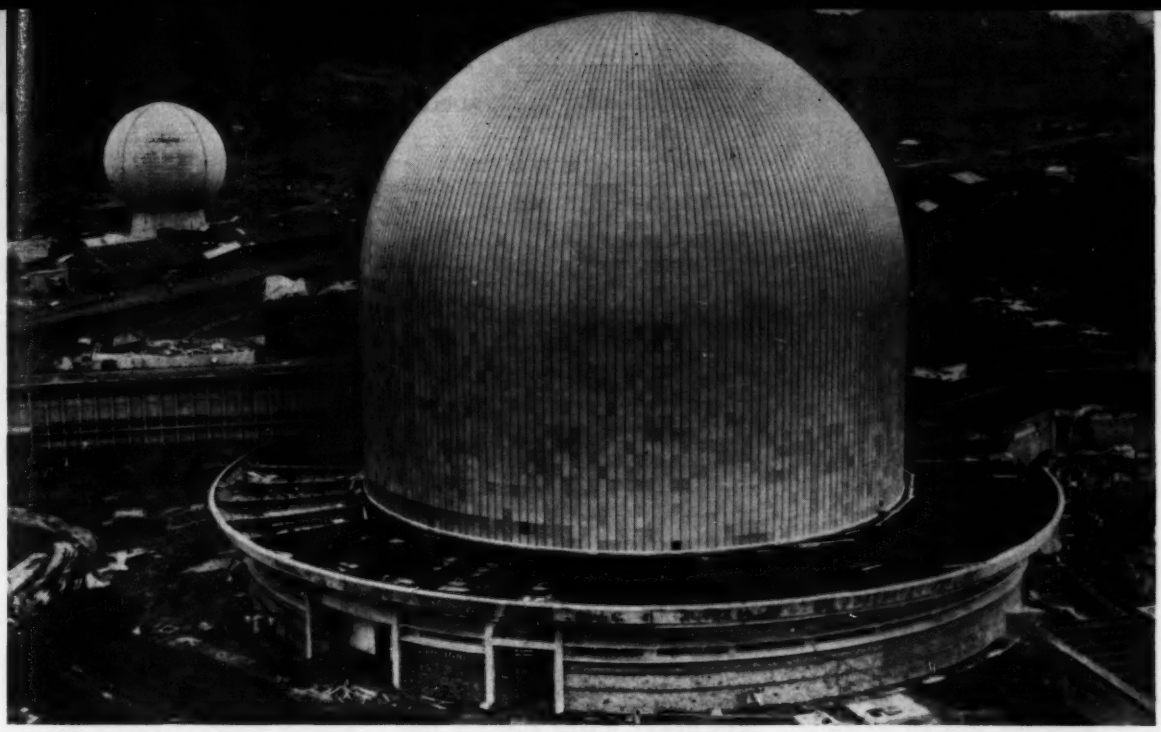
Mr. T. H. Bryce and **Mr. B. A. E. Hiley** as partners of L. G. Mouchel and Partners.

Mr. T. M. Ayres as chairman of the North Eastern Electricity Board.

Obituary

Nuclear Engineering regret to report the death of

Mr. H. G. Davey, works manager of the AEA, North Western Region, and first general manager of Windscale and Calder Hall, on August 7 at the age of 52.



The NRX-type reactor at the Indian Atomic Energy Commission research centre at Trombay, which recently achieved criticality. The tank on the left is an emergency cooling water supply.

World News

International

AMENDMENTS TO AGREEMENTS for co-operation in the peaceful uses of nuclear power have been signed by the U.S. with Argentina, Brazil, Canada, Taiwan, Greece, Israel, New Zealand, the Philippines, Switzerland, Portugal and Thailand. The Joint Congressional Committee on Atomic Energy in the U.S. has waived the statutory waiting period on the amendments.

MODIFICATIONS to Annexe V of the Euratom Treaty have been made to enable the Community to share the high flux reactor, BR-2, at Mol, with the Centre d'Etudes de l'Energie Nucleaire Belge. The convention between Euratom and the Belgian Centre provides for the joint exploitation of BR-2 for 20 years. The reactor will begin operating early next year.

CROP IMPROVEMENTS through the use of radiation were the subject of a symposium held at the invitation of the West German Government at Karlsruhe and jointly organized by the IAEA and FAO. The programme included discussions on the effects of various radiations on seeds, seedlings, and plant material.

A CATALOGUE of courses on nuclear energy in OEEC countries has been published. The catalogue covers the 1960-61 academic session and gives details of training courses in 170 Western European universities, technical high schools and research centres.

THE DURATION of the OEEC's participation in the Halden reactor project has been extended by 1½ years. Under the agreement the project expenditure for the 4½ years is fixed at just under $6 million for which additional funds of $2,137,500 from the participants are required for the extra period.

THE ANNUAL REPORT of the IAEA Board of Governors refers to the steady growth in the provision of technical assistance to member states and in the exchange of technical information. The report predicts that the Agency's operations in the coming year will continue mainly along the lines now established. The report also states that requests for equipment and supplies by members far exceeded the $125,000 budget approved in 1959 and that it is doubtful if they will be able to meet more than a part of these requests notwithstanding the additional offer of equipment worth $200,000 made by the U.S.

RAPID CONCLUSIONS to the work being done on a draft complementary convention to that of the OEEC to make provision for civil responsibility in the nuclear field is urged by the Euratom Council. It has asked each government to instruct their committees to proceed rapidly so that final decisions can be taken this month.

THE FIRST MEETING of the OEEC nuclear security tribunal established under the convention on security control in nuclear energy has taken place in Paris. The security control convention is designed to ensure that joint nuclear facilities developed with the use of the European Nuclear Energy Agency are used exclusively for peaceful purposes. The tribunal consists of seven independent judges appointed for five years by the Council.

SIX NEW PUBLICATIONS on nuclear energy have been published by the IAEA. They deal with research on controlled thermonuclear fusion, disposal of radioactive waste, use of radiation in industry and medicine and bibliographic information.

NO DECISION has yet been made by the Euratom Council concerning the establishment of a European University. The permanent representatives have been asked to continue their work in close liaison with the president of the Interim Committee, M. E. Hirsch.

United Kingdom

A SECOND nuclear power station is to be built in North Wales at Wylfa, if the M.o.P. agrees. Work will not commence before 1963, however, as, due to the revised nuclear power programme, the station will not fall under the quota to be built by 1966. Wylfa is on the north coast, one and a half miles from Cemmaes Bay.

THE NEW COLLEGE of Technology, Brunel College, under construction at Acton, is to have a research reactor. This was disclosed in the Middlesex County Council committee report recently submitted for approval. No details as to what type of reactor will be chosen have been released.

AN EXTENSIVE OVERHAUL to GLEEP, the first reactor to operate in the U.K., has recently been completed. GLEEP is graphite moderated and air cooled and has operated for nearly 13 years at Harwell. It first went critical on August 15, 1947. The instrumentation was completely renewed during the shut-down.

THE U.K. CONCERN, Turriff Construction, have been awarded the main civil engineering contract for the DRAGON project. The work will include the construction of the reactor building, control room and administration block, ancillary and technical buildings, roads, services and external work. The contract is worth more than £1 million.

Good progress is being made on the DRAGON project at Winfrith and this view shows the heavy reinforced concrete foundation.

Argentine

THE DEDICATION of new laboratories for nuclear metallurgy research has taken place at the Atomic Energy Commission in Buenos Aires. The Metallurgy division is divided into seven groups: foundry and heat treatment; fuel-element design; physical metallurgy; metallography; powder metallurgy; radio-metallurgy and reformation of metals. Equipment worth $300,000 has been included in the laboratory.

Australia

A PROFIT of £1,997,487 was made by Mary Kathleen Uranium for the first six months of this year. This is about £500,000 more than for the same period last year. Ore milled during this period amounted to 221,000 short tons producing 758,000 lb of oxide.

Brazil

THE SYMPOSIUM and meeting of the Inter-American Nuclear Energy Commission took place in Petropolis during July. A nuclear exhibit was staged by the U.S. AEC in conjunction with the meeting.

Canada

AN AGREEMENT has been signed with the U.S. AEC for co-operation in the study and development of heavy-water moderated power reactors. The U.S. will undertake some research and development work that will be specifically directed towards the heavy-water reactors to be built in Canada.

COST OF CANDU has been recalculated to be $81¼ million total including allowance for engineering, escalation, interest and commissioning. Actual construction is expected to cost around $50 million, of which the reactor, boiler and auxiliaries comprise $11.2 million. The initial fuel charge is estimated at $4.6 million.

THE BREAKDOWN of funds totalling $32,671,000, required for 1960 are itemized in the 1959/60 report of AECL. Research and operating expenditure totals $18¼ million showing an increase of $1¼ million over the previous year.

France

THE HEAVY WATER PLANT at Toulouse, established by Compagnie Francaise de l'Eau Lourde, has been inaugurated. It is designed as a pilot plant with an annual output of 2 tonnes and is intended to serve as a guide for the development of large-scale production processes.

West Germany

THE FOUR CONCERNS, Arbeitsgemeinschaft fur Kerntechnik, Deutsche Gesellschaft fur Atomenergie, Physikalische Studiengesellschaft and Atom fur den Frieden, who founded the German Atomforum, are to give up their independence and will carry on their work within the Atomforum.

AN ISOTOPE INSTITUTE is to be constructed at Freiburg University with funds supplied by the Bundes Ministry of Atomic Energy.

FULL POWER was reached on July 21 by the swimming pool reactor at Geesthacht. New elements made at Kahl are soon to be used in the 5 MW reactor built by Babcock and Wilcox of the U.S.

India

THE PRIME MINISTER, Mr. Nehru, announced in Parliament that India's first nuclear plant will definitely be built at Tarrapore in the Thana district of Maharashtra. Mr. Nehru also stated that two more 150 MW plants would be built under the next five-year plan.

THE CHAIRMAN of the Indian Atomic Energy Commission, Dr. H. J. Bhabha, received an honorary doctorate on the occasion of the tercentenary celebration of the British Royal Society. Dr. Bhabha received his degree from London University.

PERMISSION has been granted by the Government for the establishment of a unit for radioactive tracer studies at the central water and power research station at Poona. It will help in the development of isotope techniques in the solution of hydraulic problems.

Indonesia

THIRTY NUCLEAR research workers are to study at the Soviet Atomic Energy Centre. Their course will be preliminary to the establishment of a research reactor, supplied by the U.S.S.R. in Bandung.

Italy

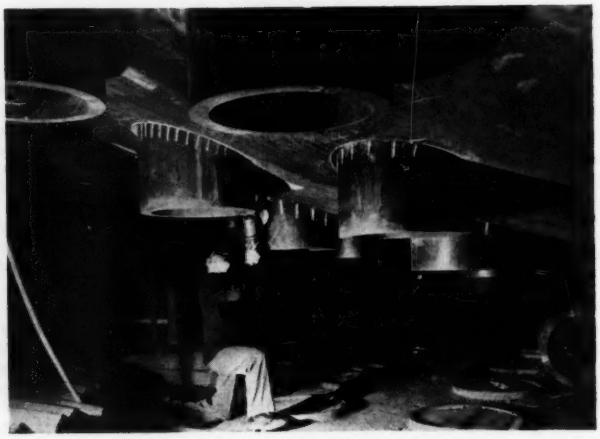
RATIFICATION of the Euratom-Italian agreement making Ispra a Euratom nuclear research centre has now been given by Parliament and the first Euratom research workers have arrived from Brussels. $40 million is to be spent over the next two years in enlarging the centre.

THE TEXT of the nuclear Bill was approved by the Senate on July 16 and is expected to be approved shortly by the Chamber of Deputies.

A CONTRACT has been signed for the joint development of an organic moderated power reactor by CNRN and Agip Nucleare. CNRN and SORIN staff will collaborate with Agip Nucleare in designing the plant.

Israel

A NEW RESEARCH DEPARTMENT has been added to the Department of Nuclear Induction at the Weismann Institute of Science. The Nuclear Induction Laboratories have been elevated to the status of a department.



The spherical pressure vessel for the A reactor at Hunterston showing some of the charge/discharge standpipes for the fuel elements in position for final welding. Charge and discharge are carried out from underneath.

Pakistan

A NUCLEAR PHYSICIST of the Pakistan Atomic Energy Commission, Dr. A. Husain, will collaborate with Dr. Gibson of CERN on the nuclear structure studies. Dr. Husain is the first Asian scientist to work at Meyrin.

THE EXHIBIT, Atoms at Work, by the U.S. AEC is to be on display in Lahore during November. The presentation, over three weeks, is part of the U.S. programme designed to acquaint people with the part nuclear energy is playing in everyday lives.

Philippines

TWO SCIENTISTS are studying at the Lucas Heights Research Centre in Australia, in preparation for establishing a nuclear centre in the Philippines. The two scientists are on a 12-month fellowship arranged under the auspices of the AEA.

South Africa

EXPORTS OF ISOTOPES produced in the cyclotron at the Council for Scientific and Industrial Research headquarters in Pretoria have been made to the Netherlands. Several other countries, including the U.K., have made inquiries about similar purchases.

ANOTHER DECREASE in exports of prescribed materials under the Atomic Energy Act was recorded for the first six months of this year. They fell by £749,199 to £24,103,705.

U.S.A.

THE POLICY of continuing irradiations has been reaffirmed by the AEC, but only if private industry are unable to meet commercial, private and overseas demand. The general policy of the Commission is to reduce and eventually eliminate its sales and service in fields where industrial sources become reasonably available.

BERYLLIUM CLADDING is to be investigated as a substitute for stainless steel in an effort to reduce costs of the 50 MWe gas-cooled heavy water reactor being studied by the Florida West Coast and East Central Nuclear Groups. Agreement for a delay of up to two years for beginning of construction (scheduled for this year) is being sought with the AEC.

THE SUPREME COURT is being asked to review the ban on Enrico Fermi construction following the refusal of the Court of Appeals to reconsider the June 10 decision.

THE McMURDO SOUND contract for a 1.5 MWe packaged BWR nuclear power plant has been awarded to Martin, conditional upon the appropriation being approved. A ceiling price of $3.95 million has been agreed. Westinghouse has conducted the studies on the secondary loop and steam generator.

ELEMENTS FOR TORY IIC of uranium beryllium oxide will be manufactured by Coors Porcelain for $3.7 million. TORY IIC is the second air cooled test reactor for the nuclear ramjet project Pluto. TORY IIA is expected to begin trials this year.

BIDS FOR CONSTRUCTION of the $5.6 million HTGC TURRET reactor (with rotating core) will be sought early next year following the acceptance of design plans submitted by W. C. Kruger and Associates for whom AMF act as nuclear sub-contractors.

UNDERWATER television equipment for making observations of a site formerly used for the disposal of low-level packaged radioactive wastes, is to be tested by the AEC. The water depth at the site is about 50 fathoms and the camera will be carried by a remote-controlled underwater vehicle.

WESTINGHOUSE report that the 110 MW nuclear station at Rowe, Mass., under construction for Yankee Atomic Power Co., will go critical shortly. The head is being put on the pressure vessel and this will be followed by a series of control rod drop tests.

INITIAL SEA TRIALS have been successfully accomplished by the latest nuclear submarine, the *Scorpion*. The submarine is of the *Skipjack* class and was designed by Westinghouse at their Bettis laboratory.

SHIPMENTS of highly enriched uranium metals totalling 1,290 kg and costing $20,640,000 have been made from Mallinckrodt Nuclear to the Argonne National Laboratory so far this year.

THE CONCLUSION of a contract is announced by the AEC with Nuclear Development for a compact reactor. The plant will be a mobile lightweight unit of about 2 or 3 MW and is expected to cost $3,585,700.

A NEW RESEARCH REACTOR capable of providing short pulses of intense nuclear energy for the study of radiation effects on electronic equipment is to be built by General Dynamics for the Army's Diamond Ordnance Fuze Laboratories. The reactor will be a special adaptation of the TRIGA type reactor and will be called TRIGA Mk-F. It is expected to cost about $1,000,000.

CRITICALITY has been achieved by the General Dynamics HTGR low power assembly at the John Jay Hopkins Laboratory. The assembly will provide details for the 40 MW HTGR plant to be built at Peach Bottom, Pennsylvania by Philadelphia Electric.

FULL POWER has been reached by the accelerator at the Brookhaven National Laboratory on Long Island. The 30 GeV accelerator cost £10,800,000 to build.

AN AUTOMATIC electronic sentry, powered by a 5-W Sr-90 battery and capable of recording data and transmitting it from a remote ground location is to be built by The Martin Company for the AEC. The device will be linked with weather instruments and will have to operate for at least two years without refuelling or servicing.

THE USE OF URANIUM in aircraft counterweights is to be permitted by the AEC without the issuance of a licence for receipt and possession of the material. Depleted uranium is used.

TEST IRRADIATION SERVICE negotiations between the AEC and Babcock and Wilcox are to be terminated. The AEC's needs for test irradiation space will be met in existing and planned AEC reactors and in two privately owned test reactors already operating. The proposed 60 MW facility has been cancelled.

A NEW SYSTEM of recording environmental levels of radioactivity at AEC and contractor installations has been established by the AEC. Public reports will be made regularly of radioactivity data collected in the vicinity of major AEC installations.

THE PRINTED PROCEEDINGS of the Atomic Industrial Forum's conference, The Role of Nuclear Propulsion in Merchant Shipping, held in Philadelphia in April, 1960, are now available at 3 East 54th Street, New York, 22.

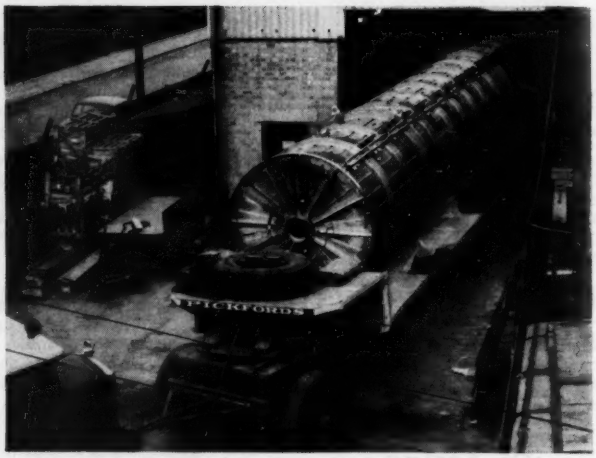
A NEW GRAPHITE PROCESS which substantially reduces the time and cost of making moulded graphite has been developed by the AEC. Called the Armour process, it was developed at the Armour Research Foundation of the Illinois Institute of Technology.

Venezuela

CRITICALITY was achieved by the 3 MW open pool type reactor at the Venezuelan Institute for Scientific Research in July. Built by General Electric the reactor is the first in Venezuela and reached criticality with 28 elements.

The low-power assembly at General Dynamics San Diego laboratory designed to study core characteristics for the HTGR project.

Industrial Notes



The 44 ft. long, 5 ft. 7 in. diameter liner, of copper ½ in. thick, hand-welded by argon-arc, for the injector accelerator of Nimrod. The liner which took 12 months to build at the London Aluminium Works in Birmingham will be installed soon at the Rutherford High Energy Laboratory, Harwell.

Blackburn Electronics are to supply temperature data handling equipment for Trawsfynydd. The installation, which is integrated into the design of the station, will operate continuously, scanning some 670 temperatures in the reactor covering, fuel elements, coolant and ancillary circuits. Each of the 670 temperatures will be checked every 70 seconds by the equipment giving an immediate indication of any departure from the normal operating levels. A printed record of all the temperatures is provided at regular intervals.

The 132 kV switching station for Hunterston is now at an advanced stage of erection. It is completely equipped with **AEI** switchgear and a new compact design has been incorporated in the circuit-breakers and there is a special arrangement of the busbars and isolators. The circuit-breakers are of the air-blast type and are rated at 2,300 MVA at 132 kV.

Allis-Chalmers have recently completed a licence agreement with **Société Rateau** of France. Under the agreement the French firm will have an exclusive licence to manufacture, use and sell A-C nuclear reactors and power plants in France and possessions and the Benelux countries. Société Rateau took part in the design and construction of the Marcoule reactors. The agreement is within the framework of the U.S.-Euratom agreements.

The completion of a new ceramic fuel development laboratory at their Greendale Laboratories is announced by **Allis-Chalmers.** The laboratory will be used to develop techniques for cladding ceramic fuels with corrosion-resistant materials.

Cambridge Instruments have merged with **Electronic Instruments.** New shares will be issued by Cambridge Instruments but Electronic Instruments will continue to trade under their own name and trade mark.

Solartron Electronic have been awarded the contract to provide the instrumentation and control apparatus for ICSE, the controlled thermonuclear research experiment to be constructed at Culham. Solartron will be responsible for the design and manufacture of the control-room apparatus which will include current and voltage measuring and recording equipment.

The six sintering furnaces supplied to the **U.K. AEA** for their uranium oxide pellet plant were built by **Wild-Barfield** under licence from **Degussa.**

Leybold-Elliott is the name of a new high vacuum concern formed by **Elliott Brothers** and **Leybolds** of Cologne. It will be a U.K. company with an initial issued capital of £100,000 in which Elliotts will have a majority interest.

A joint **British Committee for Stress Analysis** has been established following an exploratory meeting arranged by the Institute of Physics.

The **DSIR** have announced that grant aided research associations are keeping pace with the increasing research effort in industry. Fifty associations spent a total of £7.3 million last year of which the DSIR contribution was £1.7 million.

Northern Research and Engineering, representing several U.S. manufacturing concerns, have opened a research and development office in London. This concern conducts research and does industrial consulting in heat transfer, thermodynamics, fluid mechanics and related technical marketing.

An **International Seminar** will be held in Brussels on November 21-23 on the simulation of kinetic and thermal problems; simulation of chemical reactors; automatic control and methods of operational research in the chemical industry. Address is 43 rue de la Science, Brussels 4.

Consolidated Beryllium have bought the **AEA's** beryllium works at Milford Haven. The place has been operated by Murex for the Authority who disclosed in their annual report that they had overbought beryllium. Production will continue on a reduced scale.

The Industrial Products Group of Lear have received an order from **The Martin Company,** Baltimore, for 10 remotely operated automatic control systems for reactors.

Reactor operation courses on JASON are now organized by **Hawker Siddeley Nuclear Power** in two categories; basic, and advanced. Other courses, including intensive short courses, may be arranged in consultation with the reactor supervisor.

A new publication, *Nuclear Engineering Abstracts*, made its debut in August. It is a documentary journal serving the nuclear field with special emphasis on engineering. Copies may be obtained from 9 Tottenham Street, London, W.1, and the subscription per volume of four issues is £6 6s.

The Ministry of Agriculture is taking delivery of a number of monitors for the rapid determination of radioactive contamination of milk from **Plessey Nucleonics.**

Avo are to supply Harwell with a further 50 d.c. amplifiers Type 1388B, for use with ionization chambers.

A **British Standard** (B.S. 3228) for procedures for obtaining properties of steel at elevated temperatures has been produced.

A jointly financed **Steelworks Automation Unit** has been formed by **AEI** and **Davy-United.**

A **Semi-Conductor Devices Section** has been established by **BEAMA** in recognition of the rapid technical advance in semiconductors.

Thomson Ramo Wooldridge of the U.S. have formed a new company with **Intertechnique** of Paris for automatic control and industrial installations. The concern is **Compagnie Européene D'Automatisme Electronique** at 8 rue Lavoisier, Paris.

New and changes of addresses are:

The electronic installation and service department of **Ekco Electronics** have moved to the newly completed factory at Ashingdon Road, Rochford, Essex.

Industrial Guarding Equipment are now called **Industrial Control Equipment** and are located at Interlock Works, Court Road, Birmingham. Tel: Calthorpe 3114.

Solartron Laboratory Instruments are now at Cox Lane, Chessington, Surrey.

Stream-Line Filters are now at Henley Park, Nr. Guildford, Surrey. Tel: Normandy 3311.

William J. Cox have moved to London Road, Tring, Herts. Tel: Tring 3286.

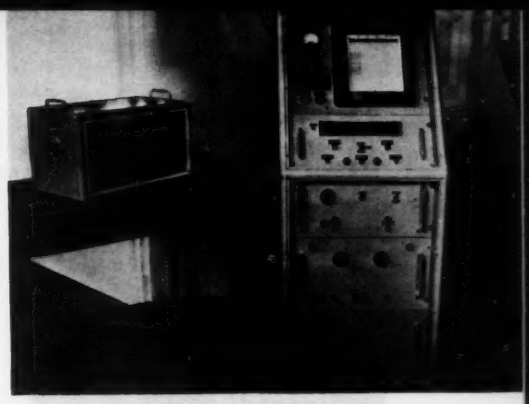
Furnival have formed a new company **Andantex** who are at Andantex House, Tamworth Street, Higher Openshaw, Manchester, 11. Tel: East 1030.

High Duty Alloys have moved their Birmingham sales office to 369 City Road, Edgbaston. Tel: Bearwood 2344.

AEL's Midland regional office is now at Gloucester House, 65 Smallbrook Ringway, Birmingham. Tel: Midland 6335.

Processes and Equipment

For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.



Sampling head and main console of the Winston beryllium monitor.

Beryllium Monitor

Automatic spectrographic analysis is the basic principle of a new beryllium monitor developed by M. S. W. and R. S. J. Webb, and P. C. Wildy, of the U.K. AEA, and now being manufactured by Winston Electronics, Ltd. Designed for continuous monitoring of industrial atmospheres, it records, every 60 sec, the beryllium aerosols present in a sample of air, and gives quantitative readings over the range of 1-75 $\mu g/m^3$, with an accuracy of $\pm 15\%$ for beryllium metal, and $\pm 30\%$ for beryllium compounds and alloys, independent of particle size.

Detection of beryllium in a sample of air is by optical excitation of the particles in triggered a.c. arc, the air flow being along the arc plasma, thus ensuring that the airborne matter remains in the excitation zone for the maximum length of time. The u.v. radiation from the excited beryllium is then monitored by a spectrograph, the intensity at 3130 Å being proportional to the beryllium concentration. The ratio of this to that of the adjacent background is then recorded.

Calibration is carried out by a sample of filtered air, to which is added a constant and known concentration of beryllium obtained from a spark discharge with a beryllium-copper electrode. Calibration runs are taken according to the programme cycle to which the apparatus is set. A convenient cycle is 25 min, in which one calibration, four "blank" runs, and 20 samples are taken. Air flow rate is 40 litre/min.

The instrument is in two sections, the sampling head containing the analysing and calibration equipment and air flow indicator and regulator, and the main console the pump, power and amplifier units and recorder.

(Winston Electronics, Ltd., Shepperton, Middlesex.)

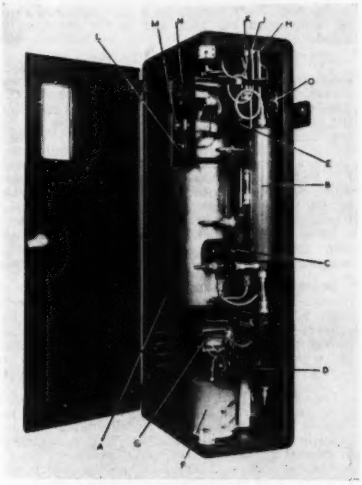
1347

Industrial Gas Purification

The purification of industrial gases, e.g., the supply of pure dry hydrogen to heat treatment furnaces, can now be carried out at some 100 ft^3/h by the Deoxo Puridryer, a recent development which combines, in one unit, the well-known Deoxo catalytic purifier and an automatic drying unit containing Linde molecular sieve. Normal commercial hydrogen, after treatment, has an oxygen content of less than 1 ppm, and a dew-point temperature of $-100°F$ ($-73°C$). The power necessary for reactivation of the drying unit is 200 W at 200/250 V 50 c/s; reactivation, which is automatic, takes approximately five hours. The platinum catalyst should last indefinitely, unless poisoned by sulphur compounds, carbon monoxide, chlorine, or certain organics. The dimensions of the unit are 32½ in. × 13½ in. × 8¾ in.

(Engelhard Industries, Ltd. (Baker Platinum Division), 52 High Holborn, London, W.C.1.)

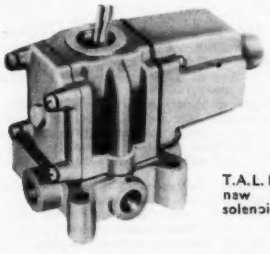
1348



The Deoxo Puridryer. A, drying unit; B, catalyst chamber; C, D, E, solenoid valves; F, converter; G, transformer; H, J, gas inlet and outlet; K, standby gas inlet; L, reactivation switch; M, pilot light; N, reactivation cycle timer; O, power connection.

Miniature Solenoid Valves

A new miniature high-speed solenoid valve, the Junior 1SGA4, is announced by T.A.L. Numatics, Ltd. Primarily intended for the control of small air cylinders, at speeds of up to 450 operations/min continuous duty, and 600 operations/min intermittently, they may be used on vacuum, or air up to 300 p.s.i., in any position. The balanced spool operating principle, without moving O-rings or elastic seals, enables operating currents to be kept low—less than 0.5 A initial current at 230 V 50 c/s—and the solenoids are continuously rated so that they may be held energized, if required. Dual exhaust ports are provided, permitting the throttling of exhaust for speed control in either direction of piston movement. Construction is in stainless steel and aluminium, and maintenance is simple.



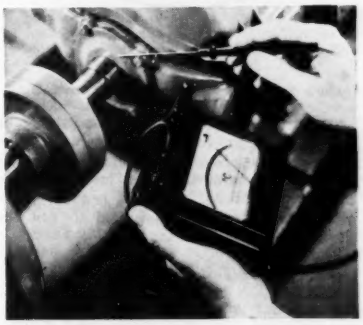
T.A.L. Numatics' new miniature solenoid valve.

(T.A.L. Numatics, Ltd., Leighton Buzzard, Bedfordshire.)

1349

Portable Temperature Indicator

Manufactured in Germany by P. Gossen, the Mavotherm portable temperature indicator is now being marketed in this country, for rapid measurement of temperatures in solids, liquids and gases. The instrument is operated from a 1.5-V dry battery which, in normal usage, will last for nearly a year, and gives indications to within $\pm 2°C$ in 3-4 sec. It has two ranges, $-20°-90°C$, and $90°-200°C$ and two probes are supplied for easy access to difficult locations.



Mavotherm portable temperature indicator.

(Aveley Electric, Ltd., Ayron Road, Aveley Industrial Estate, South Ockendon, Essex.)

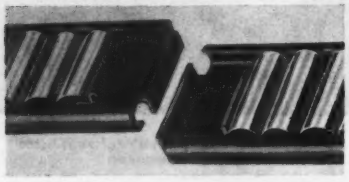
1350

Solenoid Valves

In Processes and Equipment (*Nuclear Engineering*, August, p. 376) the valves manufactured by Dewrance and Co., Ltd., under licence from the Automatic Switch Co., of New Jersey, were incorrectly referred to as Dewrance-Atco. This should, of course, read Dewrance-Asco.

Needle Roller Tracks

"Nadella" precision roller tracks, for minimizing friction on slideways, are said to have a roller diameter tolerance of 2 μ. Available in two sizes, 30mm long



Nadella needle roller tracks.

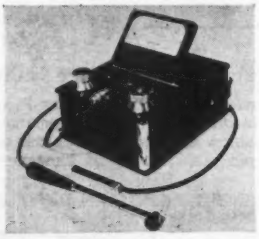
x 11.3mm wide, with 2.5mm rollers, and 48mm x 17.8mm with 3.5mm rollers, the hardened cage section has hooked ends, so that any desired length can be obtained.

(Insley Industrial Supply Co., Ltd., 21 Poland Street, London, W.1.)

1351

Battery-operated Measurements

A development of a well-known all-mains instrument, the Elcotector Mark II is designed to be truly portable, having a weight of less than 8 lb complete with batteries. Primarily intended for measuring



The Elcotector Mk. II.

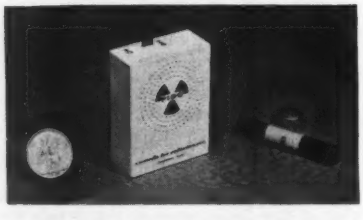
coating thicknesses on components, it can be adapted to the measurement of foil thickness, surface crack detection, hardness measurements and variations in composition of alloys, different types of pot or pencil jigs and probes being supplied to suit the particular application.

(East Lancashire Chemical Co., Ltd., Fairfield, Manchester.)

1352

Radiation Detector

FIDO (Fall-out Intensity Detection Oscillator) a miniature self-contained dose-rate alarm, developed by Control for Radiation Inc. (U.S.A.), and tested by the Home Office and the U.K. AEA, is now available in this country. A solid-state detection device operates, by means of a mercury



FIDO and its mercury battery, showing size compared with a penny.

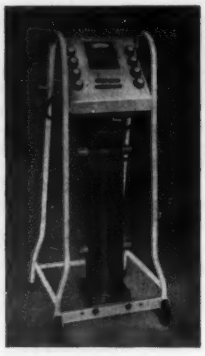
battery, an alarm giving a loud whining note, which rises in pitch as the radiation level increases. With dimensions of 3 in. x 2¼ in. x ⅞ in. and a total weight of 7 oz, FIDO is activated by levels of 300 mr/h; has been tested in temperatures between 32°F and 100°F. Battery life is over 100 hours, with indefinite shelf life.

(L. E. Simmonds, Ltd., Byron Road, Harrow, Middlesex.)

1353

Water Purifier

A mixed-bed ion exchange water treatment unit, capable of demineralizing up to 12 gal/h, is now available in portable form



Permutit Mk. 6 Deminrolit unit.

for workshop or laboratory use. The Permutit Mk. 6 "Deminrolit," designed as a free-standing unit with on-the-spot regeneration, uses Zeo-Karb 225 and De-Acidite FF as ion-exchange materials, and will produce demineralized water to B.P. "purified water" standards, the conductivity being less than 1 reciprocal megohm/cm. A conductivity tester is fitted, for continuously monitoring the quality of the output.

(The Permutit Co., Ltd., Permutit House, Gunnersbury Avenue, London, W.4.)

1354

Smallest Relays?

Weighing only 0.2 oz, the UGON relay, manufactured by Le Prototype Mecanique, near Paris, is said to be the smallest conventional electromagnetic relay in the world. With a lightweight balanced armature,

Showing the small size of the UGON relay.

operation is said to be possible at frequencies up to 800 c/s, and operating power as little as 5 mW. Contacts are of two types, the higher rating being capable of handling currents up to 0.5 A. The relays are mounted in steel cylinders, hermetically sealed, 10 mm diameter and 25 mm long, arranged for plug-in, chassis, or printed circuit mounting.

(Leland Instruments, Ltd., 145 Grosvenor Road, London, S.W.1.)

1355

BRIEFLY . . .

Johnson, Matthey and Co., Ltd., 73 Hatton Garden, London, E.C.1, have introduced a new hard gold plating bath which will deposit gold with a hardness of Vickers 120-130, and has no deleterious effect on the bonding of laminated plastics, so being particularly suitable for printed circuits. **B157**

Polypenco, Ltd., 68 Tewin Road, Welwyn Garden City, Herts, announce price reductions in their Nylatron G.S. molybdenum disulphide filled nylon which brings it into line with nylon 66. **B158**

New ranges of automatic timers, providing independent time settings for 4-12 circuits, and time ranges from 0-12 seconds up to 0-28 days, are announced by **Electrical Remote Control Co., Ltd.,** Elremco Works, Harlow New Town, Essex. **B159**

Taylor Electrical Instruments, Ltd., Montrose Avenue, Slough, Bucks, have developed a new oscilloscope, the 33a, for laboratory and radio service work. A hard time base covers a range of 2 c/s-100 kc/s; the high-gain vertical amplifier has a range up to 60 Mc/s. A stabilized power supply is incorporated. **B160**

The range of servomotors manufactured by **Evershed and Vignoles, Ltd.,** Acton Lane, London, W.4, is shortly being extended to cover industrial control applications in nominal ratings of 1/4 and 1/6 H.P. for d.c., and 1/10 H.P. for a.c. **B161**

General Controls, Ltd., 13-15 Bowlers Croft, Honywood Road, Basildon, Essex, are producing a precision rectilinear potentiometer less than 1½ in. long, with a stroke of 0.825 in., and resistance ranges of 100 to 10,000 ohms, rated at 1.5 W. A balanced arrangement of wipers reduces to a minimum contact noise and damage to the resistive element. **B162**

Graticules, Ltd., Bath House, 57 Holborn Viaduct, London, E.C.1, are producing a pocket magnifier with a built-in graticule enabling measurements to be made to within plus or minus 0.002 in. **B163**

Electro Methods, Ltd., Hitchin Street, Biggleswade, Beds, have introduced a new miniature range of components for plug and socket mounting of transistors. **B164**

Two new Philips oscilloscopes are announced by **Research and Control Instruments, Ltd.,** Instrument House, 207 King's Cross Road, London, W.C.1. The vertical scales are, respectively, 0-200 Kc/s (10 mV/cm sensitivity) and 0-5 Mc/s (100 mV/cm sensitivity). **B165**

A new ultrasonic cleaning equipment is announced by **Mullard Equipment, Ltd.,** Mullard House, Torrington Place, London, W.C.1. The total power of 500 W is distributed between twelve 40 kc/s transducers; the tank capacity is approximately 6 litres. Continuous filtration units and vapour stills for solvent recovery can be provided if required. **B166**

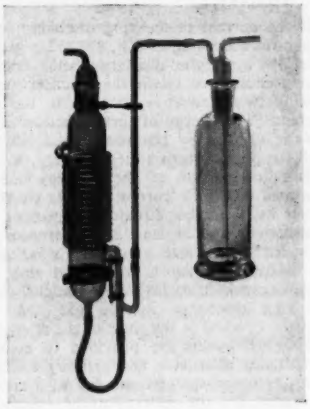
Mains failure generating sets, to operate in all climates, are being produced by **Henry Meadows, Ltd.,** Fallings Park, Wolverhampton. Of 135 kW capacity, these sets are designed to come into operation automatically to give full load within 10 seconds, at ambient temperatures down to −15°C. **B167**

The Philips Manual Welding Equipment using CO_2, marketed in this country by **Research and Control Instruments, Ltd.,** Instrument House, 207 King's Cross Road, London, W.C.1, is claimed to deposit up to 12 lb of metal per hour, using a continuous wire electrode. The CO_2 cylinders, wire reel, and feed mechanism, are mounted on a compact three-wheeled unit, so that the weight on the operator's hand is only 3½ lb. **B168**

A new range of wallplugs of the expanding sleeve type in nominal sizes of 8, 10, 12 and 14 is being marketed by **Grippo Products, Ltd.,** Henshaw Works, Oldham, Lancs. **B169**

Laboratory Gas Purification

Oxygen removal from gases on a laboratory scale can be carried out at flow rates up to 20 litres/hour by the Nilox apparatus, intended for organic synthesis, glove box work, polarography, etc., where an inert



Nilox laboratory gas purifier.

atmosphere is required. Nitrogen, for example, can, it is stated, have its oxygen content reduced from 2000 ppm to 0.2 ppm.

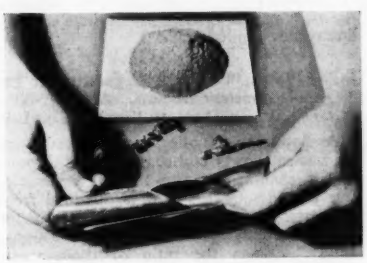
The apparatus consists of a primary absorber which has means for regeneration, and a secondary scrubber unit. Other impurities, such as CO_2, H_2S, SO_2, Cl_2, NH_3 and amines, are also absorbed.

(Southern Instruments, Ltd., Frimley Road, Camberley, Surrey.)
1356

Ductile Nuclear Materials

The Sinterwrought process, in which composites such as boron-aluminium materials are produced by mixing in powder form, sintering, and hot-working, has many advantages over conventional alloying or dispersion techniques, it is stated. In addition to small particle size, uniformity of dispersion, and extremely close tolerances in composition, many of the materials so produced retain considerable ductility. Binal, with up to 5% boron carbide uniformly dispersed in an aluminium matrix, finds a considerable use in reactor work as a burnable poison; it can be produced in continuous strip up to 5 ft wide, with very good ductility, as shown in the illustration. Other materials combining rare-earth oxides with aluminium can be produced, and composites containing oxides of dysprosium, gadolinium, samarium, europium and holmium are routine products.

(Sintercast Division, Chromalloy Corporation, 132 Woodworth Avenue, Yonkers 2, New York.)
1357



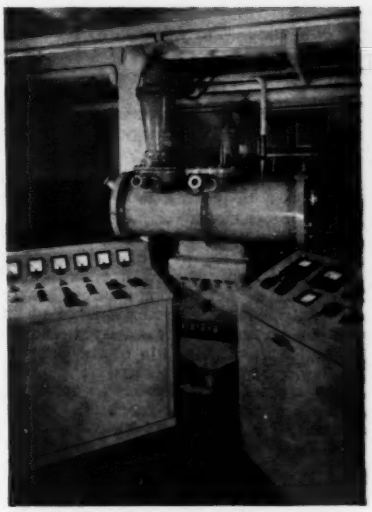
Demonstrating the ductility of Binal strip.

Electron Beam Welding

W. C. Heraeus G.m.b.H., of Hanau, Western Germany, whose products are handled by Fleischmann in this country, announce that after some 10 years' work on high-energy electron beams, they are supplying electron beam welding equipment for production purposes. An article on the technique of electron beam welding, from another source appeared in *Nuclear Engineering* for January, 1960, p.19, and it will be recalled that welding is carried out by the focusing of a beam of high-energy electrons on to the spot to be melted, in a high vacuum; the advantages including the absence of any possible contamination from atmosphere, shielding gas, or flux, and the elimination of oxidation, in addition to the ease of control of penetration and positioning of weld.

The equipment offered by Heraeus is suitable for vacua in the region of 10^{-4}—10^{-5} mm Hg, and accelerating voltages of up to 200 kV. Plants for, e.g., end-sealing of fuel elements, can be supplied with revolving magazines enabling 10 elements to be welded without breaking vacuum.

(Fleischmann (London), Ltd., Chancery House, Chancery Lane, London, W.C.2.)
1358



Heraeus electron beam welding plant, with electron gun and vacuum control panels.

CATALOGUES

The "Mini-Log" system of solid-state logic elements for control work, in which the basis of all logical functions is one simple element, backed up by power elements, is the subject of a publication by **Panellit, Ltd.,** c/o Elliott Bros. (London), Ltd., Elstree Way, Borehamwood, Herts.

The Record Electrical Co., Ltd., Broadheath, Altrincham, Cheshire, have issued a new leaflet describing their Series A Circscale instruments, with 3½-in. platform dial to reduce parallax errors. Recent improvements include the "Clearview" raised glass, which permits readings to be taken at up to 60° from the normal.

Leaflets from **Feedback, Ltd.,** Crowborough, Sussex, describe the ES 1A instructional servo system for technical colleges and training establishments.

A data sheet on a new miniature timer unit with a repetitive accuracy of 1% on normal voltage variations and ranges of 1.5-15 sec, 5-100 sec. or 15-300 sec, has been issued by **Elcontrol, Ltd.,** Wilbury Way, Hitchin, Herts.

Leaflets from the Components Division, **Miles Electronics, Ltd.,** Shoreham Airport, Sussex, describe their new precision potentiometers. The type MCD 30/FG, 3-in. diameter is fitted with 33 intermediate tappings and, by shunting sections with fixed resistors, a wide range of non-linear outputs can be obtained.

The 1959 edition of "British Chemical Plant" is to hand after delay in publication caused by the printing dispute, published by the **British Chemical Plant Manufacturers Association.** This is a bound volume of 450 pages; it gives a comprehensive view of manufacturers' plant, equipment and accessories available. Well illustrated, it contains a classified index of products and services in English, French, German and Spanish.

"Corrugaiters" and bellows in p.v.c. are described in a leaflet received from **Plysu Products, Ltd.,** Woburn Sands, Bletchley, Bucks.

A publication from **De Havilland Propellers, Ltd.,** Hatfield, Herts. describes their new Anatrol on-line process-control computer.

New publications received from **Sturtevant Engineering Co., Ltd.,** Southern House, Cannon Street, London, E.C.4, include No. 3504, "Newgate Dust Collector," No. 3505, "Fans for Mechanical Draught," No. 2804, "Bava Aerofoil Bladed Fans," and No. 7020, "Electrostatic Precipitators."

Johnson, Matthey and Co., Ltd., 73-83 Hatton Garden, London, E.C.1, have issued new publications 1460 and 1461 describing "Silver Star" precision silvered mica capacitors.

W. C. Holmes and Co., Ltd., P.O. Box No. B7, Turnbridge, Huddersfield, have issued publication No. 83, covering Bag-type Filters.

New publications from **Mullard, Ltd.,** Mullard House, Torrington Place, London, W.C.1, include a guide to cadmium sulphide cells and their application, and microwave valves.

Catalogue 84 received from **Honeywell Controls, Ltd.,** Ruislip Road East, Greenford, Middx, covers heavy duty limit switches of the microswitch type.

The revised edition of "Tomorrow's Metals Today," dealing with titanium, zirconium and beryllium, has been issued by **Imperial Chemical Industries, Ltd.,** Metals Division, Kynoch Works, Witton, Birmingham.

"Silicone Lubricating Fluids and Greases" is a booklet giving tables of physical properties, which has recently been issued by **Midland Silicones, Ltd.,** 68 Knightsbridge, London, S.W.1.

From **20th Century Electronics, Ltd.,** Centronics Works, King Henry's Drive, New Addington, Croydon, Surrey, comes a new publication on photomultiplier tubes, with hints on selection, and technical data of various types.

"Hydraulic Oils" is the title of a 74-page handbook published by **Wakefield-Dick Industrial Oils, Ltd.,** Castrol House, Marylebone Road, London, N.W.1.

Air-operated regulating units, humidity indicators and indicating and recording controllers are described in publications received from **Negretti and Zambra, Ltd.,** 122 Regent Street, London, W.1.

New publications from **Keith Blackman, Ltd.,** Mill Mead Road, London, N.17, include No. 12. "Tornado" Short Cased Axial Fans, No. 33. "Tornado" P.V.C. Fume Removal Fans, and a third edition of publication No. 37, New Centrifugal Fans, covering the range of Type AR.

"Fifty Years' Endeavour in the Service of Industry"—in this case synonymous with fifty years' development in cooling tower techniques—is a publication recently issued to mark the jubilee of the **Davenport Engineering Co., Ltd.,** Harris Street, Bradford, 1.

Reactor computers and simulators are described in literature received from **Miles Electronics, Ltd.,** Shoreham Airport, Sussex.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 829,427. Nuclear reactor control. To: U.S. Atomic Energy Commission (U.S.A.).

An element of neutron-absorbing material is oscillated in the reactor at a given frequency to produce a variation in reactivity, the period of oscillation being large compared to the reciprocal of the period of delayed neutrons, but small compared to the period of the prompt neutrons. Since the total flux in the reactor is made up of two components, due to delayed and to prompt neutrons, the ratio of the delayed-neutron component to the total, for changes in the neutron flux, represents an indication of the approach of the reactor to prompt criticality.

B.P. 829,436. Nuclear reactor. W. B. Hall. To: U.K. Atomic Energy Authority.

Refers to a fuel element with stumpy fins of graphite sealed by a protective metal shield to avoid escape of fission products.

B.P. 829,661. Nuclear reactor. To: U.S. Atomic Energy Commission (U.S.A.).

A reactor, combining the advantages of both homogeneous and of heterogeneous reactors, designed as a heterogeneous heavy-water moderated and cooled, natural uranium research reactor, and adapted to continuous removal and processing of dissolved fuel materials. The fuel elements are randomly packed uranium pellets in zirconium wire baskets in direct contact with a coolant liquid solvent (heavy water made acid with deuterium sulphate). The elements dissolve in the liquid, a portion of which is continuously removed for processing.

B.P. 829,676. Atomic power plants having heterogeneous nuclear reactors. To: Sulzer Frères S.A. (Switzerland).

Heat withdrawn from the moderator is transferred to the liquid-vapour system in at least two of a series of feed liquid preheaters, which are separated from one another by at least one preheater heated by vapour tapped off from the expansion machine. This reduces the amount of tapped vapour to the minimum required for extraction of moisture from the expansion machine, thus increasing the thermal efficiency of the plant.

B.P. 829,743. Radioactive dust monitoring device. R. Taylor, A. Scott, E. Bowes. To: Head, Wrightson and Co., Ltd.

A filter disc is periodically transferred from a hopper containing a number of such discs to an exposure chamber connected to the gas-cooling system of a nuclear power plant. From the exposure chamber the disc is transferred to a chamber containing an activity measuring detector. The filter disc is then discharged into a canister. The detector is coupled with an alarm device.

B.P. 829,779. Fuel elements for nuclear reactors. H. H. L. Ritz. To: C. A. Parsons and Co., Ltd.

A solid nuclear fuel rod is knurled or roughened at its ends. The rod is then inserted in a finned container which is subjected to hydraulic pressure to cause intimate contact between rod and container. Any creep in the fuel would tend to extend the container in unison with the fuel, avoiding local stress concentration. Shrinking would not cause loss of thermal contact between rod and container.

B.P. 829,783. Apparatus for producing beams of ions of a given element. To: Commissariat à l'Energie Atomique (France).

An envelope with a gaseous atmosphere containing an electron-emitting (hot) cathode made of the element. An electric discharge is produced in an axial magnetic field to form a plasma the positive ions of which knock out particles of the element from a negative electrode by sputtering. The ionized particles are then extracted from the envelope.

B.P. 829,958. Nuclear reactor installations. S. B. Hosegood, J. H. Swain. To: U.K. Atomic Energy Authority.

This refers to the type of reactors in which the fuel consists of a suspension or solution of fissile material in a liquid metal coolant (uranium or plutonium in bismuth). A dump tank is located below the coolant circuit. Pipe connections lead from the tank and the circuit to the high- and low-pressure sides of a pressure balancing system (e.g., a gas compressor with a blow-off valve), so as to hold the coolant level in the circuit constant.

B.P. 830,002. Electromagnetic pumps. L. R. Blake, British Thomson-Houston Co., Ltd.

A helical duct surrounds a central magnetic core and is surrounded by an annular magnetic structure. Current is applied through the duct lengthwise of its axis, i.e., transversely of the successive turns. An exciting winding surrounds the core outwardly of the duct with spiral or helical conductors connected to the end electrodes for the duct. The magnetic structure is laminated for a.c. operation.

B.P. 830,251. Gas discharge apparatus. P. C. Thonemann, R. Carruthers. To: U.K. Atomic Energy Authority.

The tendency for the constricted ring discharge within the torus of a gas discharge apparatus to touch the walls is counteracted by making the walls of a material of high electrical conductivity (aluminium) and of a thickness which is large compared with the greatest skin depth of eddy currents induced in the walls.

B.P. 830,252. Gas discharge apparatus. P. C. Thonemann, R. Carruthers, R. J. Bickerton. To: U.K. Atomic Energy Authority.

This refers to the production of controlled thermonuclear reactions in a toroidal vessel containing gas, the vessel having thick conductive walls with at least one electrically insulating transverse joint. A pinched high-current unidirectional pulsed ring discharge is established in the gas. A magnetic field set up within the vessel parallel to the continuous axis thereof reduces spatial instabilities of the discharge channel.

B.P. 830,253. Production of mechanical power from thermonuclear reactors. R. Carruthers. To: U.K. Atomic Energy Authority.

If the current in the ring discharge in an apparatus according to B.P. 830,252 is greater than 10^6 amp, the discharge fields become strong enough to retain the reaction nuclei, leading to an effective increase in the ring current. The energy of these reaction nuclei can be utilized by electromagnetic reaction with the plasma during the discharge, so that a large proportion of their energy can be absorbed from the current ring as electrical power by a suitable circuit arrangement. A transformer and at least one alternator are provided to energize a primary winding of the transformer for a constricted ring discharge current to retain reaction nuclei within the ring discharge in the gas. A flywheel is coupled to the shaft of the alternator and switch means are provided to connect periodically alternator and primary winding. The alternator shaft is coupled to a second alternator for the generation of electricity. A set of alternators may be used to be connected cyclically to the primary winding.

B.P. 830,254. Gas discharge apparatus. R. J. Bickerton. To: U.K. Atomic Energy Authority.

Windings to establish a magnetic field within a toroidal vessel are arranged coaxially with the gas containing vessel to establish a magnetic field in order to reduce spatial instability.

B.P. 830,255. Production of nuclear power. P. C. Thonemann, M. J. Poole, J. D. Lawson, J. H. Tait. To: U.K. Atomic Energy Authority.

Additional power is produced from neutrons passing walls and liners of a toroidal vessel as described in B.P.830,252, by enveloping the vessel with a first blanket containing material (uranium-238) fissionable by fast neutrons, and by a second blanket, containing lithium-6, to absorb neutrons from the first blanket with the production of tritium.

B.P. 830,256. Production of electrical power from thermonuclear reactors. R. Carruthers. To: U.K. Atomic Energy Authority.

Constitution of a resonant circuit by a condenser and transformer in connection with a gas discharge apparatus according to B.P. 830,252, from which current may be drawn.

B.P. 830,471. Metal welding method. To: Commissariat à l'Energie Atomique (France).

Protection against oxidation by effecting the welding in a rarefied atmosphere through electronic bombardment.

B.P. 830,661. Protective apparatus for gas cooled nuclear reactors. A. E. T. Nye. To: British Thomson-Houston Co., Ltd.

A first signal voltage representative of the nuclear power output is obtained through an ion chamber, a second signal representative of the total gas flow is obtained from apparatus responsive to the speeds of the coolant circulators (inductor type alternators). When the ratio of these signal voltages exceeds a certain value the shut down mechanism is actuated.